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THESIS

IMPROVING SITUATIONAL AWARENESS IN THE COUNTER-IED FIGHT WITH THE UTILIZATION OF UNMANNED SENSOR SYSTEMS

by

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June 2009

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13. ABSTRACT (maximum 200 words)

An organized and thorough systems design framework is necessary to successfully address large-scale, complex problems, such as the utilization of unmanned sensor technologies to provide situational awareness (SA) in the counter-improvised explosive device (C-IED) fight. An appropriate systems engineering design process was used to develop such a framework, as the completion of the first two phases—problem definition and solution design—provides a basis for analysis of alternatives and a design recommendation. This process generated the following problem statement: Design a system that, through the use of unmanned sensors, provides effective and efficient SA to the commander in a C-IED scenario. By effective, the system must maximize the ability to process sensor imagery and detect, classify, identify, and counter IEDs. To be efficient, the system must address important characteristics of operational suitability and survivability. Thus, providing SA, maximizing operational suitability, and maximizing Soldier survivability are the primary objectives in the effective and efficient employment of unmanned sensors in C-IED. Three physical alternatives were generated and synthesized: baseline, near-term, and long-term. Each alternative consisted of a combination of sensors, satellites, and unmanned systems to ensure that the top-level SA functions are addressed. Each alternative's basic specifications, battlefield flow (highlighting each unmanned sensor's use for observe, process information, and understanding the environment), and drawbacks are addressed.

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IMPROVING SITUATIONAL AWARENESS IN THE COUNTER-IED FIGHT WITH THE UTILZATION OF UNMANNED SENSOR SYSTEMS

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ABSTRACT

An organized and thorough systems design framework is necessary to successfully address large-scale, complex problems, such as the utilization of unmanned sensor technologies to provide situational awareness (SA) in the counter-improvised explosive device (C-IED) fight. An appropriate systems engineering design process was used to develop such a framework, as the completion of the first two phases—problem definition and solution design—provides a basis for analysis of alternatives and a design recommendation. This process generated the following problem statement: Design a system that, through the use of unmanned sensors, provides effective and efficient SA to the commander in a C-IED scenario. By effective, the system must maximize the ability to process sensor imagery and detect, classify, identify, and counter IEDs. To be efficient, the system must address important characteristics of operational suitability and survivability. Thus, providing SA, maximizing operational suitability, and maximizing Soldier survivability are the primary objectives in the effective and efficient employment of unmanned sensors in C-IED. Three physical alternatives were generated and synthesized: baseline, near-term, and long-term. Each alternative consisted of a combination of sensors, satellites, and unmanned systems to ensure that the top-level SA functions are addressed. Each alternative's basic specifications, battlefield flow (highlighting each unmanned sensor's use for observe, process information, and understanding the environment), and drawbacks are addressed.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

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LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

AEHF	advanced extremely-high frequency
AO	area of operations
ARV-RSTA	armed robotic vehicle-reconnaissance, surveillance, and target acquisition
BAI	battlefield air interdiction
BCT	brigade combat team
BSB	brigade support battalion
C2	command and control
CALL	Center for Army Lessons Learned
CCIR	commander's critical information requirements
CENTCOM	central command
CIA	Central Intelligence Agency
C-IED	counter-improvised explosive device
COP	common operational picture
COTM	communications on the move
CP	command post
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOTMLPF	doctrine, organization, training, material, leadership and education, personnel, and facilities
DP	decision point
DSCS	Defense Satellite Constellation System
EEFI	essential elements of friendly information
EFP	explosively formed penetrator
EHF	extremely-high frequency
EO	earth observation
EOD	Explosive Ordinance Disposal
FCS	Future Combat System

FEP	Fleet SATCOM package
FFIR	friendly forces information requirement
FIDO	Field Integrated Design and Operations
FM	field manual
FOB	forward operating base
FOUO	for official use only
ft	feet
FY	fiscal year
G-BOSS	Ground-Based Operational Surveillance Systems
Gbps	gigabytes per second
GCS	Ground Control Station
GPS	global positioning system
HMMWV	high mobility multipurpose wheeled vehicle
hp	horsepower
HQ	headquarter
hrs	hours
HSI	human systems integration
HUMINT	human intelligence
IED	improvised explosive device
INCOSE	International Council on Systems Engineering
IND	improvised nuclear device
INS	inertial navigation system
IR	infrared
IRAM	improvised rocket assisted munitions
JAUS	joint architecture for unmanned systems
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JLENS	joint land attack cruise missile elevated netted sensor
km	kilometer
kts	knots
lbs	pounds

LDR	low data rate
LED	light-emitting diode
LOC	line of communication
LOS	line of sight
LTC	Lieutenant Colonel
LTG	Lieutenant General
MARCbot	multifunction, agile, remote controlled robot
Mbps	mega bits per second
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MDARS-E	mobile detection assessment and response system-exterior
MDR	medium data rate
METT-T	Mission, enemy, terrain, troops, and time available
MILSATCOM	Military Satellite Communications System
mins	minutes
MITT	military transition team
MND-B	Multi-National Division-Baghdad
MOP	measure of performance
MOGAS	motor gasoline
MRAP	mine resistant ambush protected
MSR	main supply route
MSTAR	man-portable surveillance and target acquisition radar
MULE	multi-functional utility logistics equipment
MUM	manned and unmanned
NPS	Naval Postgraduate School
NSA	National Security Agency
NSCC	Naval Satellite Communications Course
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OP	outpost
PEP	polar EHF package

PIR	priority information requirements
PMESII	political, military, economic, social, information, and infrastructure
RAID	rapid aerostat initial deployment
RAM	reliability, availability, and maintainability
RAND	research and development corporation
RBD	reliability block diagram
RCIED	radio control improvised explosive device
RSTA	reconnaissance, surveillance, and target acquisition
S3	training officer
SA	situational awareness
SATCOM	satellite communication
SHF	super-high frequency
SIGINT	signal intelligence
SIPRNET	secure internet protocol router network
SUGV	small unmanned ground vehicle
TNT	trinitrotoluene
TOC	tactical operations center
TSAT	transformational satellite
TTP	tactics, techniques, and procedures
UAS	unmanned aircraft system
UFO/E	ultra-high frequency follow-on enhanced
UFO/EE	UHF follow-on EHF enhanced
UGV	unmanned ground vehicle
UHF	ultra-high frequency
VBIED	vehicle-borne improvised explosive device
VOIED	victim-operated improvised explosive device
WGS	wideband global system
XO	executive officer

EXECUTIVE SUMMARY

An organized and thorough systems design framework is necessary in order to successfully address large-scale, complex problems, such as the utilization of unmanned sensor technologies to provide situational awareness (SA) in the counter-improvised explosive device (C-IED) fight. An appropriate systems engineering design process was used to develop such a framework.

This research begins by exploring the background and motivation of the use of improvised explosive devices (IEDs), unmanned sensor technology, and SA through literature review and input from appropriate stakeholders. Then, the current satellite, unmanned aircraft systems (UASs), unmanned ground vehicles (UGVs), and camera systems used in theater are described, along with their basic physical and performance capabilities. Future systems are described for consideration in the generation of alternatives. A common operational scenario faced in the C-IED environment concerns distinguishing IEDs from debris alongside roadways within a unit's area of operations, and this serves as the overall context for the development of this framework.

A systems engineering design process begins with the problem definition phase, which begins with stakeholder analysis, and culminates with the development of a functional and objectives hierarchy for providing SA. The revised problem statement, which serves as the top-level objective, is as follows:

> Design a system that, through the use of unmanned sensors, provides effective and efficient SA to the commander in a C-IED scenario. By effective, the system must maximize the ability to process sensor imagery and detect, classify, identify, and counter IEDs. To be efficient, the system must address important characteristics of operational suitability and survivability.

Thus, providing SA, maximizing operational suitability, and maximizing Soldier survivability are the top-level objectives in the effective and efficient employment of unmanned sensors in C-IED. Quantitative measures, defined as measures of performance (MOPs), are proposed for each of these qualitative functions. The objectives hierarchy, shown in Figure 1, shows the relationship of the three top-level objectives and their sub-

objectives, and serves as the foundation for assessing the selected alternatives. A description of these objectives and their associated metrics is below.

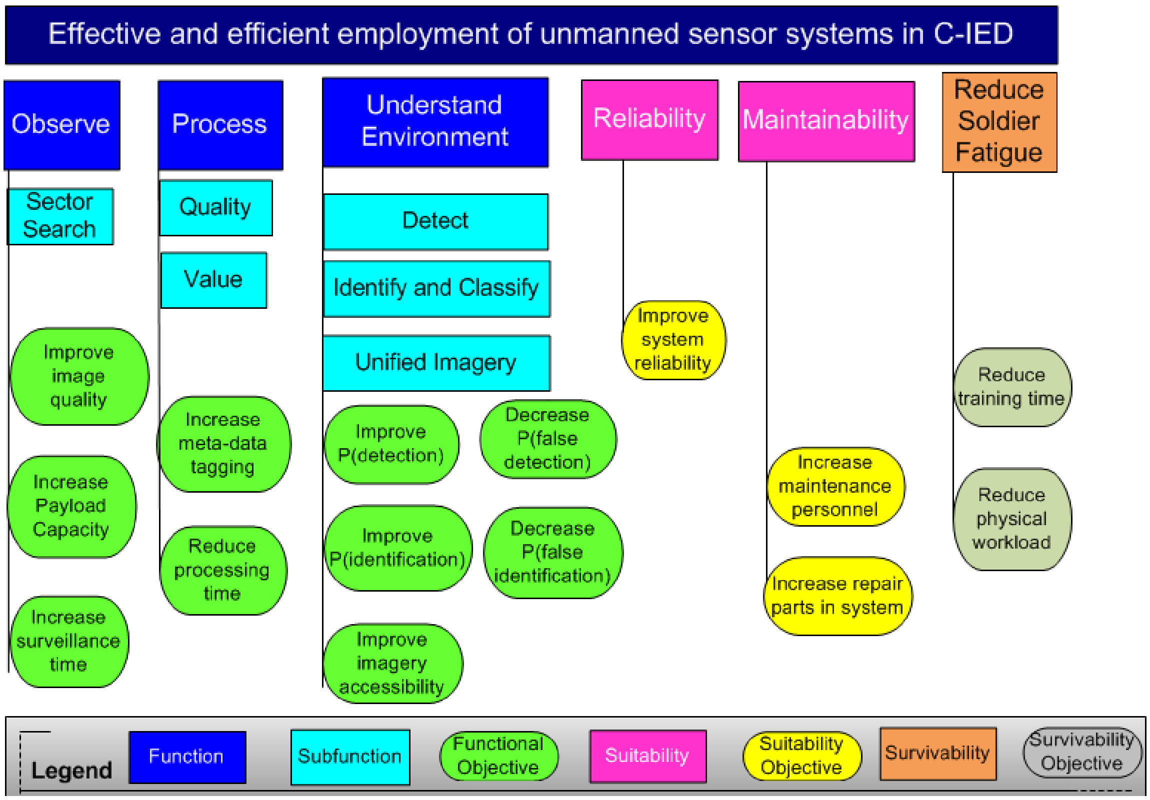

Figure 1. Objectives hierarchy

The objective *observe* is achieved via human intelligence (HUMINT) and signal intelligence (SIGINT). Squads on patrol, Soldier interaction with the local populace, interrogation of detainees, and informants are all forms of HUMINT. While HUMINT is an important component of observation on the battlefield, this research focused solely on the utilization of SIGINT. Manned and unmanned sensors are the key components of SIGINT and provide a commander with either still imagery or streaming video of designated target or observation areas. Sensors have varying payloads, resolution capabilities, bandwidth restrictions, and available spectrums in which to perform surveillance operations. Larger payloads on sensor systems mean more capability to carry a variety of equipment. The MOPs for the observe function are quality of imagery, surveillance coverage, and sensor payload capacity.

The data received from unmanned systems must be *processed* in order to provide commanders with useful information. Information consists of two critical attributes: value and quality (Perry, 2000). Information has value if "it informs the commander and thereby adds to his knowledge of the combat situation" (Perry, 2000, p. 3). Information has value in providing SA if it answers or assists in answering commander's critical information requirements (CCIR). Information quality consists of three components: accuracy, timeliness, and completeness (Perry, 2000). Therefore, when providing SA in combat operations, it is imperative to utilize functions that contribute to providing a commander with both valuable and quality information.

Accurate and complete information in combat operations is enhanced by unmanned sensors when data fusion occurs to combine all available information (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008). Data fusion is the process of putting together information obtained from many heterogeneous sensors, on many platforms, into a single composite picture of the environment. Emerging technology allows for imagery and videos to be fused using meta-data tagging, which are tags describing the data to enable discovery, and include time, location, classification, and sensor calibration. Tags allow data gathered from separate sensors to be combined in a meaningful way.

Accurate and complete information is of no use to the commander if it arrives too late. The speed in which information is transmitted, processed, and analyzed greatly impacts a commander's ability to act effectively and decisively on the battlefield. The MOPs for the process function are to increase the number of sensors with meta-data tagging capability and decrease processing time.

Commanders need useful and valuable information in order to *understand their environment*, which includes detecting IEDs, enemy activity, friendly forces, local activity, as well as recognizing disturbed soil or tracking an insurgent's activity patterns. Unmanned sensors can be used to identify and classify potential IEDs or investigate disturbed soil to negate risk to personnel. Sensor systems that provide real-time imagery for all units operating within an area of operations greatly enhances shared common operational picture (COP). The MOPs for understanding the environment are probability

of detection, probability of false detection, probability of identification, probability of false identification, and number of units with real-time imagery.

Operational suitability is not intended as a physical attribute of the system, or what the system does, but instead measures the characteristics of the system. Operational suitability is the degree to which a system can be satisfactorily placed in field use with respect to reliability, availability, and maintainability (RAM), supportability, human systems integration (HSI), and interoperability. This research focuses on the impact of *reliability* and *maintainability* in the emplacement of unmanned sensor systems in the C-IED fight. These two components were selected because they are important considerations from both the system and individual Soldier perspective. Equipment utilized in combat must be able to perform at a high performance level for a sustained period of time. When new or updated systems are introduced without sufficient operational testing or with an expedited time line, military maintenance capabilities are limited. The MOPs for operational suitability are system reliability, percentage of unit maintenance personnel trained to repair equipment, and percentage of repair parts available in unit level logistics system.

In general, Soldier survivability consists of six key components: reduce fratricide, reduce detectability of the Soldier, reduce probability of being attacked, minimize damage, minimize injury, and reduce physical and mental fatigue (Payan & Zigler, 2008). It terms of providing SA in the C-IED fight utilizing unmanned sensors, the key component of maximizing Soldier survivability is *reducing physical and mental fatigue* on the Soldier. Reducing physical and mental fatigue is measured by the physical, cognitive, and workload constraints placed on the Soldier by the system (Payan & Zigler, 2008), so that the MOPs for reducing Soldier fatigue are training time and physical workload.

The second phase of the systems engineering process is solution design, and consists of generation of alternatives and solution analysis. To ensure that all the significant system functions are adequately addressed in the generation of alternatives, as described in the functional hierarchy and reviewed in the objectives hierarchy, the system design elements are broken down into partitions or sectors. Three alternative designs are

generated: baseline, near-term, and long-term. The baseline system consists of current unmanned sensors, and satellites used by the Army; the near-term system includes systems that have completed research development tests and are being prepared for fielding, and the long-term system combines satellite systems and unmanned sensor systems that may be available in the next 10-15 years. Each alternatives' basic specifications, battlefield flow (highlighting each unmanned sensor's use for observe, detect, and battle management), and drawbacks are addressed. As an example, Alternative 1, the baseline system, is shown in Figure 2.

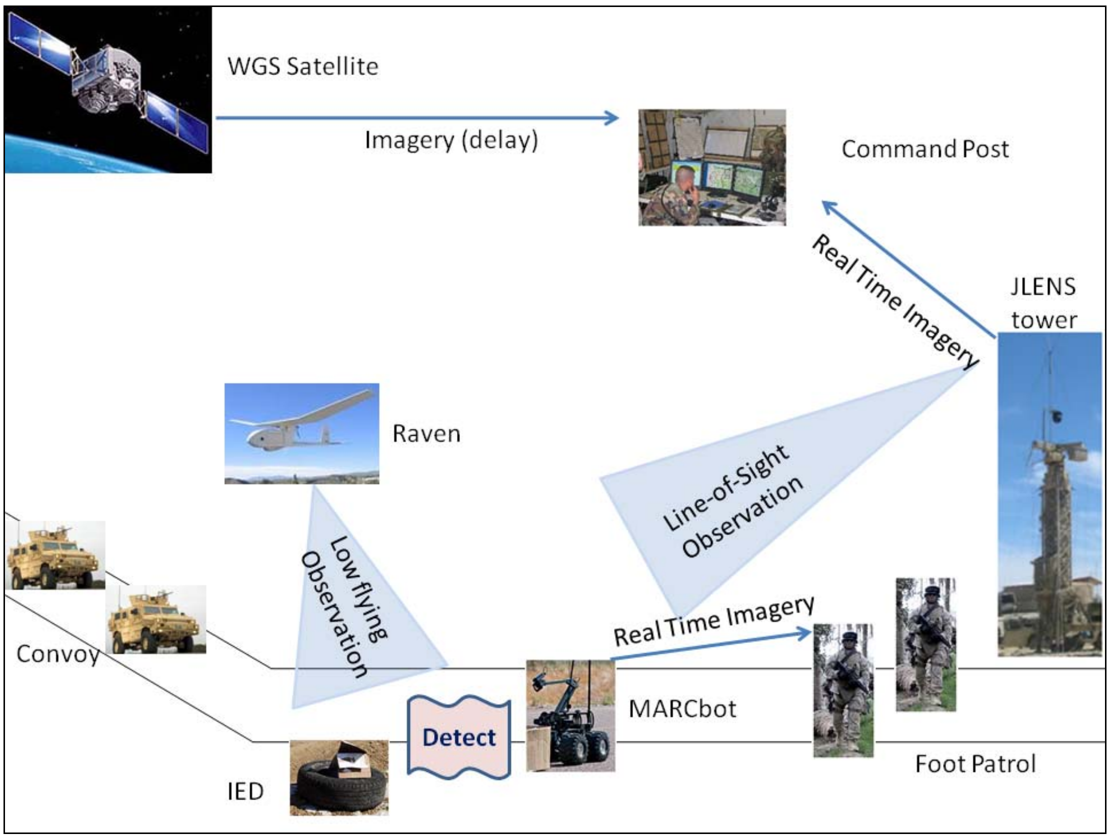

Figure 2. Alternative 1: Baseline

The systems engineering framework developed for this research is only a starting point for improvements in meeting the war-fighters' desires to provide SA in the C-IED fight. Although the methodology used in this research provides a framework for pairing war-fighter desires with current and future unmanned sensor systems, further alternatives

may be generated for use in decision making and solution implementation. Recommendations for future research in the area of improving SA in the C-IED fight through unmanned sensors include performance, cost, and risk analysis. These analyses could evaluate the performance and effectiveness of system alternatives in providing SA in the C-IED fight, based on the needs analysis, objectives hierarchy, and associated evaluation metrics developed in this thesis. The three alternatives could be evaluated and analyzed with reference to various operational scenarios.

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I. INTRODUCTION

A. PURPOSE AND OVERVIEW

This research focuses on considerations for increasing situational awareness (SA) in defeating the enemy (determining an attack is in progress, and stopping the attack during the execution phase or prior to completion) in the counter-IED (C-IED) fight, using unmanned sensor technologies. The Joint Improvised Explosive Device Defeat Organization (JIEDDO) defines C-IED as the collection of efforts and operations, including offensive and defensive measures, taken to prevent insurgency cells from proliferating improvised explosive devices (IEDs), detect or neutralize IEDs once they are emplaced, mitigate the effects of an IED event, or train our forces to execute C-IED measures. It also includes intelligence operations to defeat the IED network, as well as respond to the IED threat and its effects. This research develops a framework that includes a focused set of system functions and requirements within the context of a limited operational concept, as well as alternative solutions that integrate several technological systems. Follow-on research based on this effort should include a systems analysis of alternatives through appropriate modeling and simulation, cost and risk analysis of each alternative, and an implementation plan.

B. BACKGROUND AND MOTIVATION

1. Improvised Explosive Devices (IEDs)

The *Joint Tactics, Techniques, and Procedures for Antiterrorism Manual* defines an IED as:

> A device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic, or incendiary chemicals and designed to destroy, incapacitate, harass or distract. It may incorporate military stores, but is normally devised from nonmilitary components. (Department of Defense, 1998, p. GL-3)

IEDs are not a new guerilla tactic, with instances dating as far back as the Belarussian Rail War, when Belarussian guerrillas utilized both command-detonated and delayed-fuse IEDs to derail thousands of German trains from 1943-44 (Belarus.by, 2009). IEDs are not a standard military weapon and have a human involved in the loop who decides when to arm the device or when to trigger it. They have been used by various ethnic, cultural, and religious groups, but historically were rarely used as a primary means of inflicting mass casualties. However, quickly emerging technologies have allowed today's insurgents to stay one step ahead of American forces' tactics and capabilities. IEDs have been responsible for the deaths of over 1,800 United States servicemen and women in Iraq, and the numbers are quickly rising in Afghanistan (Icasualties.org, 2008).

While the number of IED incidents in Iraq decreased by 79%, from its peak of 2,600 per month in March and June of 2007 to 555 in August 2008, incidents in Afghanistan, as seen in Figure 3, are on the rise.

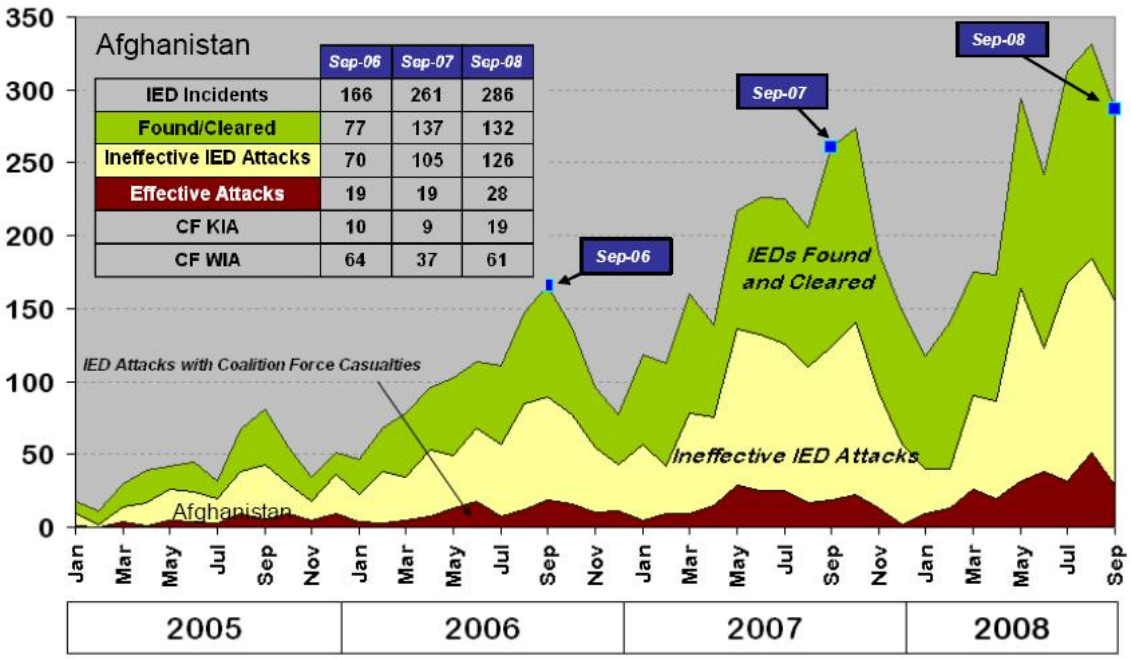

Figure 3. IED incidents in Afghanistan (From: Afghan Conflict Monitor, 2008)

The emergence of explosively formed penetrators (EFPs) and the deep-buried or underbelly bomb account for a disproportional 70% of U.S. bombing deaths in Iraq

(Atkinson, 2007). Unlike traditional IEDs, which produce a fragmentation or blast to do damage, EFPs are directional weapons that form a projectile that follows a linear path from a canister. This new type of IED will not be the last development by insurgents to negate our C-IED tactics and technology.

It is important to note that there is a difference between an IED event and an IED campaign. A few individual IED events, such as pipe bombs or car bombs on U.S. soil, are very different from an IED campaign in which an enemy organization is established to emplace many IEDs over an extended period of time. In individual IED events, security and police can be used to try to identify the people responsible for the attack. In an IED campaign, there is an organized system or network that will continue to attack and allows for a number of different ways to approach the problem. An IED campaign is a part of insurgency warfare and will be continued only as long as it is successful and it advances the strategy of the insurgency. Stopping an IED campaign may not stop the insurgency, and even if the attacks are successful, the campaign may be stopped if it is not successful in furthering the goals of the insurgency. A military effort to counter IEDs could be successful in the narrow sense of reducing the impact of IEDs and still be counterproductive in countering the insurgency.

2. Unmanned Sensors

Unmanned systems have traditionally been used to assist commanders in the development of a common operational picture (COP). The Objective Force COP is the single set of meaningful information desired by military commanders to expedite the decision-action cycle (Waltz & Llinas, 1990). Unmanned sensors are ideal for assisting in the development of a COP in the military's dull, dirty, or dangerous missions. Dull missions are often defined as long-duration sorties, and using unmanned aircraft systems (UASs) for reconnaissance frees up aviation crews for other missions. Dirty missions include flying UASs through nuclear clouds or operating an unmanned ground vehicle (UGV) in a contaminated environment. Use of unmanned systems in dirty missions allows for longer observation periods and minimizes human exposure. Dangerous missions include explosive ordinance disposal (EOD) missions and the use of ground

robotics to detect or disarm IEDs. The use of ground robotics has resulted in the neutralization of over 11,100 IEDs since 2003 (Office of the Secretary of Defense, 2007).

Congress has outlined two specific goals for the development of UASs and UGVs: "By 2010, one third of the aircraft in the operational deep strike force should be unmanned and by 2015, one third of the Army's Future Combat Systems (FCS) operational ground combat vehicles should be unmanned" (Office of the Secretary of Defense, 2007, p. 6). In order to fill these requirements, a proper architecture in which to examine possible solution sets must be developed.

One of the primary issues is how these assets are being used in theater versus what they were designed to do. While unmanned sensors can be used to attack the IED network, many units in Iraq are using UASs primarily for finding IEDs that are already emplaced (Hodge, 2006). Interestingly, this is in direct conflict with both General Ronald Keys' and Lieutenant General Raymond Odierno's vision for the use of UASs. General Keys, the Air Component Commander for U.S. Joint Forces Command, stated that "looking for IEDs in Iraq in that fashion is not the best way to stop attacks" (Lowe, 2007). LTG Odierno, currently the Commander of Multi-National Force-Iraq, stated that units should "use UAVs to trace enemy firing teams back to caches and assembly areas" and that "units that adopt a proactive, creative approach that synchronizes all available reconnaissance and surveillance systems will degrade IED networks in their area" (Odierno, 2007, p. 3).

There has been a significant amount of research conducted on IED countermeasures. The Center for Army Lessons Learned (CALL) has published numerous For Official Use Only (FOUO) and classified documents covering current tactics, techniques, and procedures (TTPs) used in theater and C-IED technologies. Using UASs primarily as a means of detecting IEDs, however, was found to be ineffective in a classified thesis at the Naval Postgraduate School (Brock & Gammache, 2007).

Another emerging area of research in the C-IED arena is the idea of defeating the network via social network analysis. The use of human intelligence and social

interactions is gaining momentum and is becoming a large area of C-IED focus. However, due to time constraints, this research focuses solely on unmanned sensor technologies.

3. Situational Awareness (SA)

The Army defines SA as:

> Knowledge and understanding of the current situation which promotes timely, relevant and accurate assessment of friendly, competitive and other operations within the battlespace in order to facilitate decision making. An informational perspective and skill that fosters an ability to determine quickly the context and relevance of events that are unfolding. (Headquarters, Department of the Army, 2004, p. 171)

A simpler definition of SA is "knowing what is going on around you" (Endsley & Garland, 2000, p. 5). In combat situations, this includes reconnaissance, precision target identification, and designation and battle management. The development of an operational environment is a composite of the conditions, circumstances, and influences that affect employment of capabilities and bear on the decisions of the commander. This environment includes physical areas and factors of land, air, sea, and space as well as the cyber domain of information (Department of Defense, 2006). The U.S. joint community uses a systems perspective on the political, military, economic, social, information, and infrastructure (PMESII) elements of an operational environment. This operational environment is complex, with additional immeasurable elements such as the culture, perceptions, beliefs, and values of the actors operating within the environment. SA is the intangible measure in the center of analysis, rather than a discrete assessment of a specific issue or action. A detailed discussion of SA, and how it is specifically related to defeating IEDs, is found in Chapter III.

C. RESEARCH QUESTIONS

Primary Research Question: What material solutions may be utilized in conjunction with unmanned sensors to increase SA in the C-IED fight?

Subsidiary Research Question: What are the system functions that address SA in the defeat of IEDs?

Subsidiary Research Question: What metrics best represent the attainment of important functions and objectives regarding SA in the C-IED fight?

D. METHODOLOGY

While there is a general consensus that the utilization of a systems design process allows for an organized approach to generate and evaluate various alternatives, there is not a commonly accepted definition of systems engineering. The International Council on Systems Engineering (INCOSE) defines it as:

> An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. (Parnell, Driscoll, & Henderson, 2008, p. 167)

Parnell, Driscoll, and Henderson define systems engineering as:

> The systems engineering thought process is a holistic, logically structured sequence of cognitive activities that support system design, systems analysis and systems decision making to maximize the value delivered by a system to its stakeholders for the resources. (2008, p. 9)

Finally, according to Blanchard and Fabrycky in *Systems Engineering and Analysis*, systems engineering is " good engineering with emphasis on using a top down approach, definition of system requirements, utilization of a life-cycle orientation and an interdisciplinary or team approach" (2006, p. 18).

There are several published methodologies in which to apply the systems engineering process. Each of these design processes includes an organized and structured approach in which to solve a given problem. This research follows the systems engineering process described by Parnell, Driscoll, and Henderson and utilized at the Systems Engineering Department at the United States Military Academy and is depicted

in Figure 4. There are four major phases that are iterative in nature and assist in organizing the problem: problem definition, solution design, decision making, and solution implementation. This research focuses on the first and second phases. The first phase, problem definition, consists of three key components: conducting stakeholder analysis, performing functional analysis, and constructing a value model. The second phase, solution design, is the generation of ideas, refinement, and the generation and screening of alternatives (Parnell, Driscoll, & Henderson, 2008).

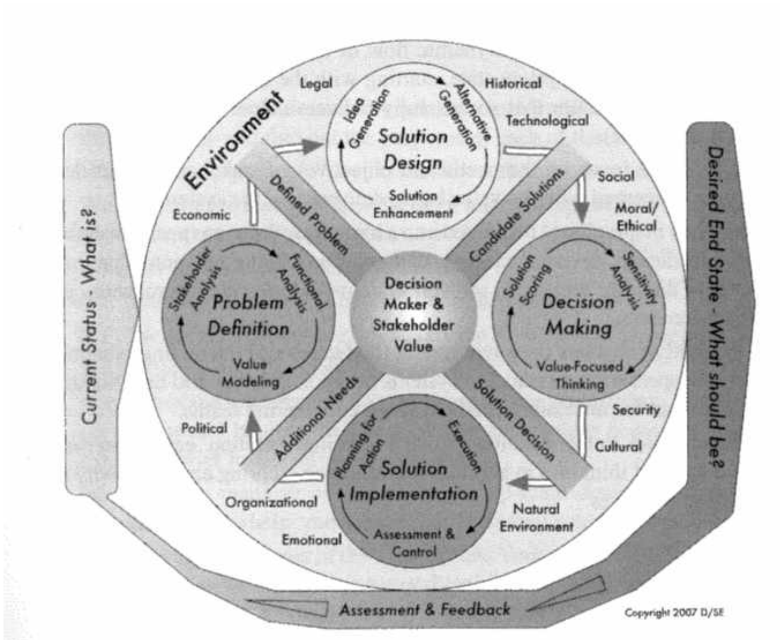

Figure 4. Systems decision process (From: Parnell, Driscoll, & Henderson, 2008)

This research transforms stakeholder requirements and customer needs into top-level functions. These functions are paired with objectives and measured using value measures. Development of a qualitative model leads to a generation of alternatives that will be evaluated using a quantitative value model. The value model allows for the analysis of existing and near-term unmanned sensor technology against the stakeholder-approved value measures.

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II. COUNTER-IED (C-IED) TECHNOLOGY

A. IMPROVISED EXPLOSIVE DEVICE (IED) CATEGORIES

The three ways of classifying or categorizing IEDs are by trigger type, warhead type, or delivery mechanism. There are three primary trigger types or means of detonating an IED: radio control (RCIED), victim-operated (VOIED), and infrared (IR). Joint Publication 1-02 (Department of Defense, 2001) defines two warhead classification types: the IED and the improvised nuclear device (IND). The differentiating factor is that the IND contains radioactive material (Department of Defense, 2001). The most common delivery mechanisms used by insurgents in Iraq and Afghanistan are car/vehicle-borne IEDs (VBIEDs), EFPs, suicide bombers, platter charges, and, more recently, improvised rocket assisted munitions (IRAM). IRAMs are propane tanks filled with explosives and powered by 107mm rockets (Londono, 2008).

An EFP is a special type of shape charge used to penetrate armor effectively at stand-off distances. It has a liner in the shape of a shallow dish, and when the explosive detonates, as seen in Figure 5, the EFP liner is generally folded into its final rod-like shape for maximum penetration of armor plating.

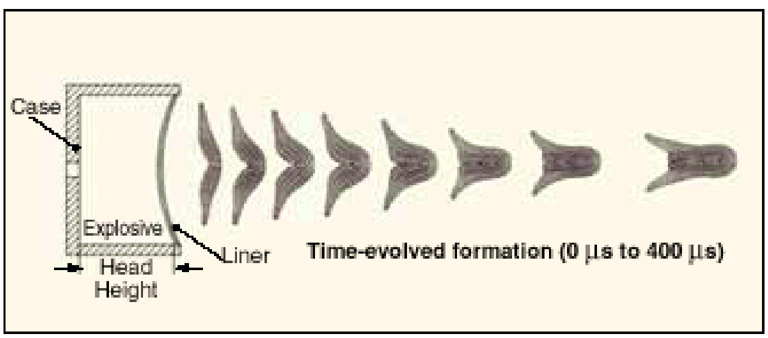


Figure 5. Formation of an EFP warhead (From: Londono, 2008)

Sophisticated EFP warheads have multiple detonators that can be fired in different arrangements, causing different types of waveforms in the explosion. This results in a long-rod penetrator, an aerodynamic slug projectile, or multiple high-velocity fragments.

The EFP uses explosives to form a molten copper penetrator instead of using an explosive blast or solid metal penetrator, and are therefore extremely dangerous, even to the new generation of Army Mine Resistant Ambush Protected (MRAP) vehicles, which were designed to withstand an antitank mine (Eisler, 2007). An EFP can penetrate a thickness of armored steel equal to half the diameter of its charge for a copper or iron liner, and armored steel equal to the diameter of its charge for a tantalum liner (GlobalSecurity.org, 2008).

As our technology improves, the insurgents alter, improve, and make bigger and deadlier devices. Shape charges, VBIEDs, and now EFPs, are just the beginning of the enemy's methods. There is a real and growing concern that IEDs will become the weapon of choice for other terrorists and insurgents worldwide (Wilson, 2007).

B. CURRENT COUNTER-IED (C-IED) TECHNOLOGIES

Brigade Combat Teams currently deployed in support of Operation Iraqi Freedom (OIF) or Operation Enduring Freedom (OEF) in Afghanistan have a mix of unmanned systems to utilize in their tactical planning. Most deploy with a mix of satellites, UASs, UGVs, and ground cameras or surveillance systems in order to have persistent surveillance and communication capabilities.

1. Satellites

> Twenty-five hundred years ago the Chinese general Sun Tzu wrote, 'If you know the enemy and know yourself, you need not fear the result of a hundred battles.' But how are U.S. soldiers, operating covertly in unfamiliar and hostile territory, to know where their allies are, where their enemies are, and what each is doing? How are they to receive commands and report status? The answer is satellite communications. (Martin, 2001/2002, p. 3)

Today's Army depends heavily on satellites for developing a COP. Satellites provide a means for voice communications, video imagery, and still imagery to be projected across the battlefield. Current Military Satellite Communications Systems (MILSATCOMs) include Ultra-High Frequency (UHF), Super-High Frequency (SHF),

and Extremely-High Frequency (EHF) capabilities. UHF is traditionally used by early entry Army forces that are highly mobile and may not have access to large ground terminals. Ideally, these early entry forces would utilize communications on the move (COTM); however, today's satellite configurations only provide communications on the pause (Headquarters, Department of the Army, 2003). SHF systems are a primary choice for data transfer for numerous reasons: They have a low probability of intercept due to their usage of narrow beams; they have beyond-line-of-sight high-speed voice, data, and imagery flow; and they provide a high-speed rate of transfer (Naval Satellite Communications Course [NSCC] Study Guide, 2003). EHF systems complement both the UHF and SHF constellations, but provide greater robustness against jamming and scintillation and electromagnetic pulse protection (NSCC Study Guide, 2003).

Current SHF MILSATCOM systems include the Defense Satellite Constellation System (DSCS) and the Wideband Global System (WGS) (or the Global Broadcast Service). The DSCS currently has five primary satellites and six residual satellites providing worldwide coverage. The WGS has 8 times the power of the DSCS and 11 times the bandwidth. There will be three WGSs in orbit by the summer of 2009, which is the equivalent of 36 DSCSs (Racoosin, 2006).

EHF was developed to maximize utilization of wide bandwidth and to provide protection options that UHF and SHF lack. Current EHF MILSATCOM systems include the Fleet satellite communication (SATCOM) package (FEP), Ultra-high Frequency Follow-on Enhanced (UFO/E), the UHF Follow-on EHF Enhanced (UFO/EE), Polar EHF Package (PEP), and Milstar. The Advanced EHF is the successor to the Milstar satellite system and will be the Department of Defense's (DoD) primary system for protected satellite communications (Headquarters, Department of the Army, 2003).

The demand for bandwidth on the battlefield has resulted in an ever-growing gap between capabilities and requirements, as shown in Figure 6, and this demand does not seem to be slowing. Unconstrained demand represents the expectations of operational users and the anticipated demand. The demand generated by sensors and the needs of the user has resulted in projected limitations that will be imposed on the capacity of the ground terminals and the military SATCOM area coverage and capacity.

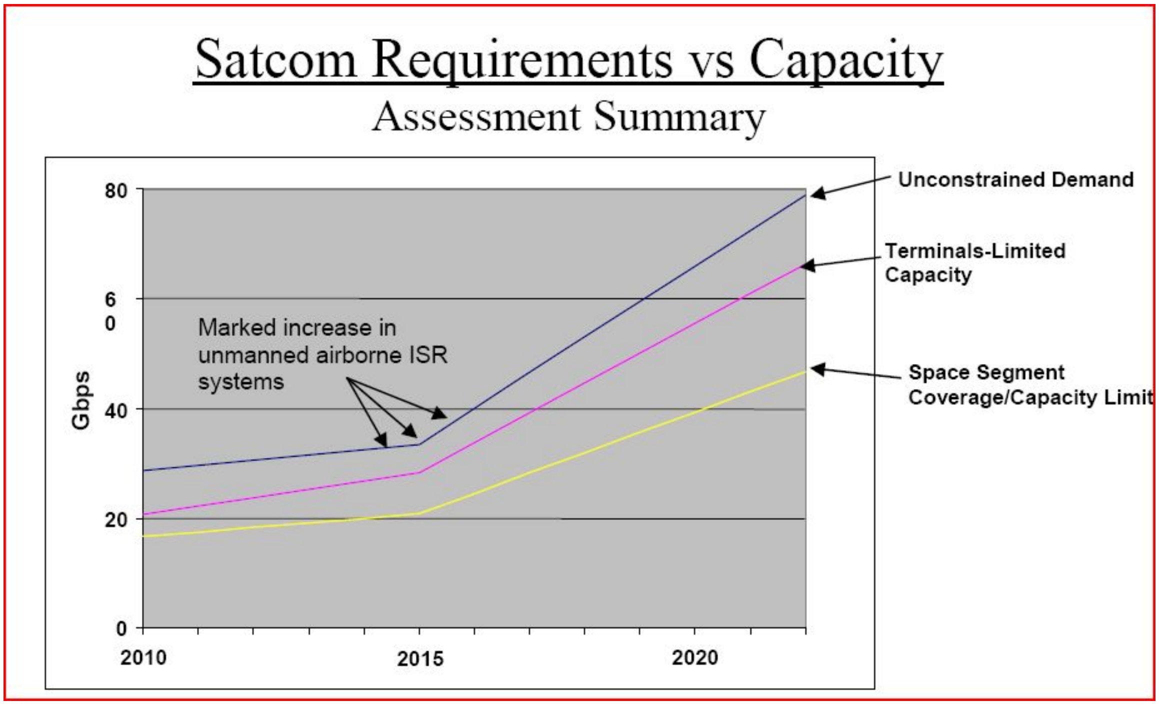


Figure 6. Satcom requirements vs. capacity (From: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008)

The Pentagon's recent postponement of the transformational satellite (TSAT) contract award until Fiscal Year (FY) 2010 means the satellite package will not be available until FY2019, thus greatly limiting the Army's planned use of the Future Combat System and future bandwidth accessibility (Shala-Esa, 2008). Many of the UASs in testing phase were designed to utilize the faster uplinks and data transfer of the TSAT constellation. Customer requirements have not changed, but the proposed satellite resources and capabilities available to the warfighter in the near future have. With the Army's desire for COTM, some of the unmanned sensors currently in development phases may need to be re-engineered to utilize the current satellite configurations or adjusted to function using less bandwidth.

2. Unmanned Aircraft Systems (UASs)

> To date, Army UAS have flown over 375,000 hours and nearly 130,000 sorties in support of combat operations in Iraq and Afghanistan. Capabilities of Army UAS have evolved from a theater intelligence asset

to primarily tactical roles such as surveillance, reconnaissance, attack, targeting, communications relay, convoy overwatch, and cooperative target engagement through manned and unmanned (MUM) teaming. The Army is employing UAS as an extension of the tactical commander's eyes to find, fix, follow, facilitate, and finish targets. Army UAS missions are integrated into the maneuver commander's mission planning, at the start, as a combat multiplier in the contemporary operational environment. (Kappenman, 2008, p. 22)

Unmanned aircraft are designed with four primary modules: flight control, payload control and product dissemination, weapon's employment, and SA. For purposes of this research, the payload control and product dissemination model are of greatest interest. This includes the electro-optical sensors (still and motion imagery in visible, infrared, multispectral, and hyper spectral sensors), synthetic aperture radar, signals intelligence sensors, and communications relay equipment (Office of the Secretary of Defense, 2005).

The RQ-7 Shadow, shown in Figure 7, is primarily managed at the brigade level. It uses an electro-optic/infrared imaging sensor turret and has an endurance capability of 5 hours. Each Shadow 200 system includes three unmanned aerial vehicles UAVs, two ground stations, and support vehicles for equipment and personnel. The Shadow's physical and performance characteristics are listed in Table 1 (Goebel, 2009).

Figure 7. RQ-7 Shadow (From: GlobalSecurity.org, 2005b)

RQ-7B Shadow Characteristics			
Length	11.2 ft	**Wing Span**	14 ft
Gross Weight	375 lbs	**Payload**	60 lbs
Endurance	7 hrs	**Ceiling**	15,000 ft
Data Links	LOS C2	**Speed**	38 hp
	LOS Video	**Fuel Type**	MOGAS

Table 1. RQ-7B shadow characteristics (From: Goebel, 2009)

The RQ-11 Raven, as shown in Figure 8, is managed at the battalion level and is often passed down to companies. The Raven is launched by hand and can fly at an altitude of 1,000 ft at speeds up to 52 kts. It can fly using global positioning system (GPS) waypoint navigation or can be navigated from a ground station using a remote control. The Ravens have an analog infrared night vision camera and a color video capability (Goebel, 2009). The Raven's physical and performance characteristics are listed in Table 2.

Figure 8. RQ-11 Raven (From: Simpson, 2005)

Raven Characteristics			
Length	3.4 ft	**Wing Span**	4.3 ft
Gross Weight	4 lbs	**Payload**	2 lbs
Endurance	1.5 hrs	**Ceiling**	1,000 ft
Data Links	analog	**Speed**	52 kts
		Fuel Type	Battery

Table 2. Raven characteristics (After: Goebel, 2009)

3. Unmanned Ground Systems (UGVs)

Brigade Combat Teams (BCTs) often have a mix of robotics including the multifunction, agile, remote-controlled robot (MARCbot), TALON, and sometimes have the field integrated design and operations (FIDO) system upgrades. MARCbots, as seen in Figure 9, are often pushed down to the maneuver company level and divided up among platoons. MARCbots are small, remote-controlled robots that use an attached camera to seek out, identify, and confirm possible IEDs.

Figure 9. MARCbot inspecting suspicious package (From: Clifton, 2005)

The MARCbot has an observation distance of greater than 300 feet and a low-light camera with light-emitting diode (LED) arrays for nighttime missions. The camera rises to a vertical height of 3 feet and has the capability to tilt forward for looking into potential danger areas. The MARCbot is powered by standard batteries and is valued at less than $10,000 per system (Exponent Engineering and Scientific Consulting, 2008).

The TALON Robot system, as shown in Figure 10, is found with the EOD companies that are often attached to the BCTs. These robots weigh less than 100 pounds, are man-portable, and move on small treads with seven speed settings. The TALON is controlled with a joystick, has both audio and video capability, and a mechanical arm (Grabianowski, 2005). The TALON is a rugged robot, with a broad array of sensor packages and a quad-screen display. It can hold up to four color cameras including night

vision, thermal, and zoom options. TALON robots can move as fast as a running Soldier and are easy to maintain (Foster-Miller Corporation, 2007).

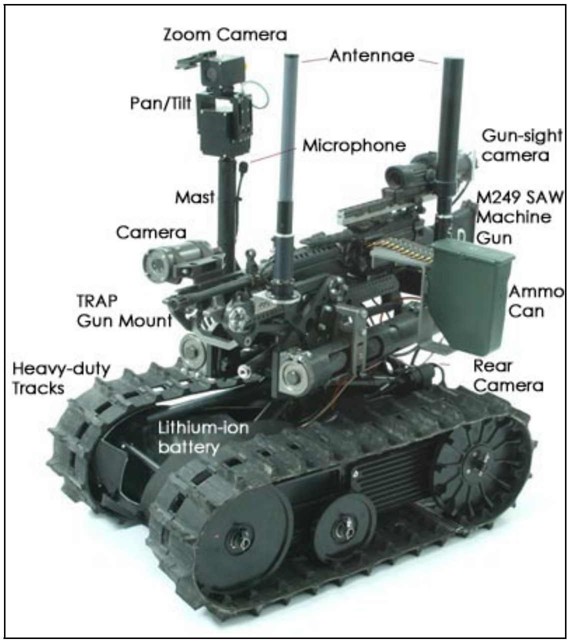


Figure 10. TALON robot (From: Grabianowski, 2005)

The FIDO system add-on, as shown in Figure 11, is one of the smallest explosive detectors and uses vapor detection comparable to that of bomb dogs.

Figure 11. FIDO (From: Sacramento L5 Society, 2006)

FIDO is a handheld system that can be fully or partially integrated with either MARCbots or TALON systems. When fully integrated, the sensor head and its communication box are attached to the robot. The sensor head can be removed and used for other handheld operations. Regardless of the configuration, all detections are displayed on the robot's operator's control unit (ICX technologies, 2008).

4. Camera Systems

BCTs rarely have sole control over large unmanned camera systems; however, they often have their own joint land attack cruise missile elevated netted sensor (JLENS). A JLENS consists of a surveillance system and a fire control system, and provides long-duration, over-the-horizon, and wide-area coverage for battlefield commanders. The key component of the system is the sensor, which has a zoom lens, laser range finder, and provides infrared coverage at night. The majority of the systems being used in theater are combined with a Rapid Aerostat Initial Deployment (RAID) tower shown in Figure 12. RAID towers are a mix of 30, 60, and 84 quick erect telescope mast towers. JLENS has also been paired with a large blimp system (see Figure 13) to provide sensors

high above the battlefield. In both configurations, the JLENS camera sensor is networked to a Base Defense Operations Cell, which projects the video feed with digitized map overlays (Burlas, 2004).

Figure 12. JLENS and RAID tower
(From: United States Army Program Executive Office: Missiles and Space, 2005)

Figure 13. JLENS on blimp (From: Burlas, 2004)

The Ground-Based Operational Surveillance System (G-BOSS) is a force protection, camera-oriented, day/night, expeditionary tool that provides the ability to detect, track, display, record, assess, deny, and store video to counter the threat of IEDs and disrupt insurgency activities (Marine Corps Combat Development Command, 2007); see the G-BOSS operational construct as shown in Figure 14. G-BOSS referred to throughout this research is composed of a RAID 107-foot mobile tower with two cameras: a Star SAFIRE IIIFP and a T-3000, a Man-Portable Surveillance and Target Acquisition Radar (MSTAR) sensor, and a Ground Control Station (GCS).

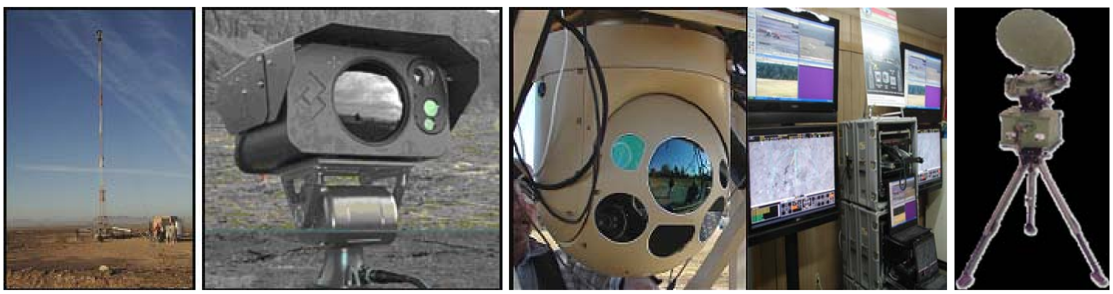


Figure 14. G-BOSS components from left to right: RAID tower, T-3000, Star SAFIRE IIIFP, RGS, MSTAR (From: Marine Corps Combat Development Command, 2007)

C. PROPOSED FUTURE COUNTER-IED (C-IED) TECHNOLOGY

1. Satellites

As the demand for high-resolution streaming video grows and commanders at all levels on the battlefield require real-time information, a bandwidth gap continues to grow as well, as discussed in the previous section and seen in Figure 15. The military's proposed answer to these demands is the Advanced EHF satellite constellation and the transformational communications satellite. Both systems will provide greater protection and faster uplink/downlink speeds.

The advanced extremely-high frequency (AEHF) satellite, shown in Figure 15, is the military's planned next-generation, strategic, protected command and control (C2) satellite program and is the successor to Milstar II. AEHF combines the functionality of the Milstar low data rate (LDR) and medium data rate (MDR) payloads into a much

smaller integrated EHF communications package. Compared to Milstar, the AEHF system program improvements include higher data rates (8.192 Mbps), an upgraded terminal segment, additional nuller antennas, increased throughput, additional uplink and downlink channels with interoperable, protected, anti-jamming, low probability of intercept and low probability of detection communications (NSCC Study Guide, 2003).

Figure 15. Milstar III (From: Katzman, 2006)

The TSAT, shown in Figure 16, will consist of a five-satellite constellation, with a sixth as a spare, which will provide troops on the ground with orbit-to-ground laser communications. TSAT was designed provide users with a high data rate, jam-resistant, worldwide, secure coverage to replace the DoD’s current satellite system and supplement AEHF (GlobalSecurity.org, 2005c). Imagery from a UAV that would typically take 2 minutes to process using the Milstar II system or radar imagery from a Global Hawk, which traditionally takes about 12 minutes to process, would both take less than a second using TSAT (Katzman, 2006). TSAT will be the first satellite system to provide CMOT with a small receiver. The TSAT system consists of the space segment (satellites), and the integrated ground stations and networks (Katzman, 2006). The TSAT system, shown in Figure 16, has been deemed so important to future sensor integration that its immediate establishment was listed as one of two primary findings in the October 2008 final report of the Defense Science Board and the Intelligence Science Board Joint Task Force on Integrating Sensor Collected Intelligence (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008).

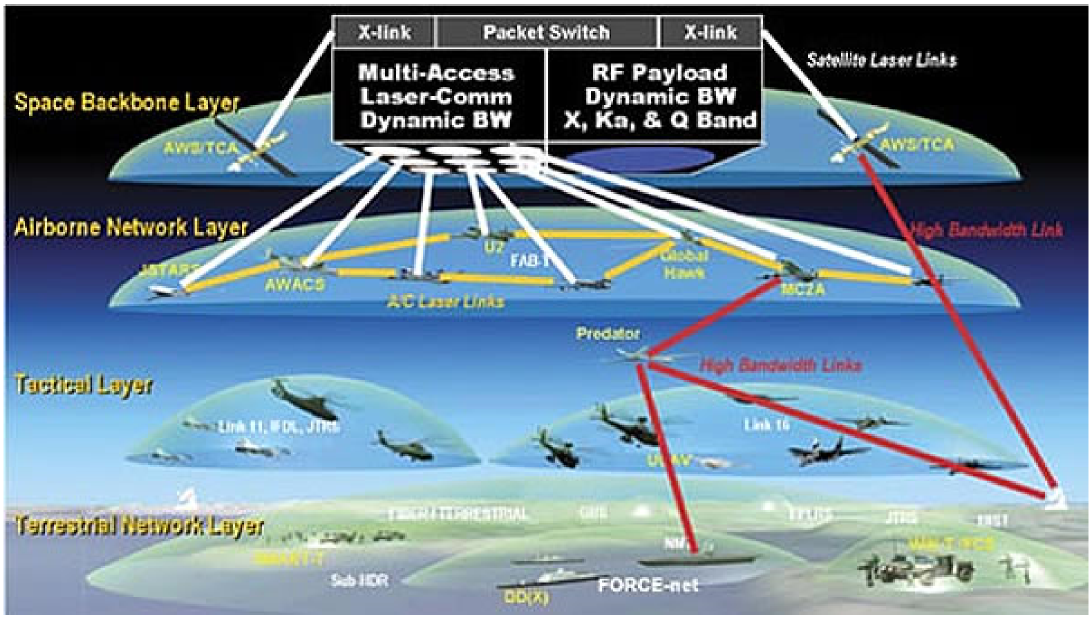


Figure 16. TSAT Concept (From: Katzman, 2006)

2. Unmanned Air Systems (UASs)

Due to the inability to reasonably discuss the remarkably high number of unmanned aircraft being tested, developed, and marketed to the United States Military, this research will focus on the systems proposed in the Army's FCS framework (see Table 3) and those outlined in the DoD's UAS Roadmap.

FCS Unmanned Aircraft				
	Platoon	**Company**	**Battalion**	**Brigade**
Aircraft	Raven (interim)	TBD	Shadow (interim)	Fire Scout
Weight	5-10 lbs	100-150 lbs	300-500 lbs	>3,000 lbs
Endurance	50 mins	2 hrs	6 hrs	24-hr continuous operations
Radius	8 km	16 km	40 km	75 km
Transport	Manpackable (35-lb system)	2-Soldier Remount	2-Man Lift	100 m x 50 m Recovery Area

Table 3. The Army's proposed FCS unmanned aircraft (From: Office of the Secretary of Defense, 2005)

The Army's FCS includes the Raven, Shadow, and Fire Scout for use in the various unit levels of a BCT. The unmanned aircraft for company level use has not been projected.

The Raven is currently undergoing an upgrade from its analog datalink. A new digital data link has undergone two years of testing, with experimentation conducted at White Sands Missile Range, New Mexico. The updated data link will provide a four-time improvement in available channels, increased range, improved video quality, relay capability, and encryption (Olean, 2008).

The DP-5X Wasp, shown in Figure 17, is an FCS-compliant system and has successfully completed development and test milestones. The system is a modular design that allows the aircraft to be separated into components and is man-transportable. It takes two operators to launch and can fit into a high mobility multipurpose wheeled vehicle (HMMWV) system. Its primary design focus is reconnaissance, surveillance, and target acquisition (RSTA) and can also be used as a communication relay platform. The DP-5X Wasp has a universal payload interface that is field changeable, a secure communication relay, earth observation/infrared (EO/IR) day and night, and a laser designator (Dragonfly Pictures, 2009).

Figure 17. DP-5X Wasp (From: Dragonfly Pictures, 2009)

DP-5X Wasp Characteristics					
Length	11 ft	**Rotar Span**	10.5 ft	**Endurance**	4.8 hrs
Gross Weight	475 lbs	**Payload**	75 lbs	**Speed**	110 kts
Fuel Capacity	165 lbs	**Fuel Type**	Heavy Fuel	**Ceiling**	15,000 ft
Power	97 hp				

Table 4. Wasp characteristics (After: DragonFly Pictures, 2009)

The XPV-1 Tern, shown in Figure 18, is a possible FCS system. The Tern is powered by a two-stroke piston engine and has a steerable nose and main gear, with tires suitable for rough terrain. The Tern utilizes a GPS navigation system, and a microwave datalink to transmit video imagery and sensor data. The standard payload includes a forward- and side-looking color TV camera with optional battlefield air interdiction (BAI) sensor upgrades available (IR, pan tilt, jammers) (Parsch, 2005).

Figure 18. XPV-1 Tern (From: Parsch, 2005)

XPV-1 Tern Characteristics					
Length	9 ft	**Wing Span**	11.4 ft	**Endurance**	4 hrs
Gross Weight	130 lbs	**Payload**	25 lbs	**Speed**	68 kts
Fuel Capacity	28 lbs	**Fuel Type**	MOGAS	**Ceiling**	10,000 ft
Data Links	LOS C2	**Power**	12 hp	**Landing**	Runway
	LOS Video	**Frequency**	L/S band, UHF	**Sensor**	EO or IR

Table 5. Tern characteristics (After: Parsch, 2005)

3. Unmanned Ground Systems

The Armed Robotic Vehicle-Reconnaissance, Surveillance, and Target Acquisition (ARV-RSTA), shown in Figure 19, uses sophisticated on-board sensors to detect, recognize, and identify targets. It is designed to remotely provide reconnaissance in urban environments and comes with a direct-fire weapon system. The ARV-RSTA comes with an ANS with GPS with inertial navigation system (INS), perception sensors for obstacle detection, and avoidance and autonomous navigation algorithms. It also has a medium-range EO/IR with 16-ft mast, is joint architecture for unmanned systems (JAUS) compliant and is compatible with the Multi-functional Utility Logistics Equipment (MULE) unmanned system (Office of the Secretary of Defense, 2007).

Figure 19. ARV-RSTA (From: Office of the Secretary of Defense, 2007)

The MULE, shown in Figure 20, is an unmanned platform that provides transport of equipment and supplies in support of dismounted maneuver. The 2.5-ton class vehicle is a projected part of the FCS and comes in three variants: transport, armed robotic vehicle assault, and counter-mine. The MULE can also communicate with UASs to

provide additional sensor information in the development of a COP. The MULE has day and night thermal, infrared, and forward-looking imaging systems, which are all JAUS compliant (GlobalSecurity.org, 2005a).

Figure 20. MULE (From: GlobalSecurity.org, 2005a)

The small unmanned ground vehicle (SUGV), shown in Figure 21, is a man-packable small robot system that weighs less than 30 lbs. The SUGV is designed to operate in urban operations and can be reconfigured on-site for various mission sets. It will incorporate a lightweight day or night sensor suit capable of providing remote surveillance images, is JAUS-compliant, and part of the FCS network (Office of the Secretary of Defense, 2007).

Figure 21. SUGV (From: Roush, 2008)

4. Camera Systems

Each JLENS Orbit, shown in Figure 22, consists of two systems: a surveillance system and fire control system, which includes elevated, long-range surveillance radar and elevated, high-performance fire control radar. Each radar is integrated onto a large aerostat, connected by a tether to the ground-based mobile mooring station and communications processing group (Staff Writers, 2008).

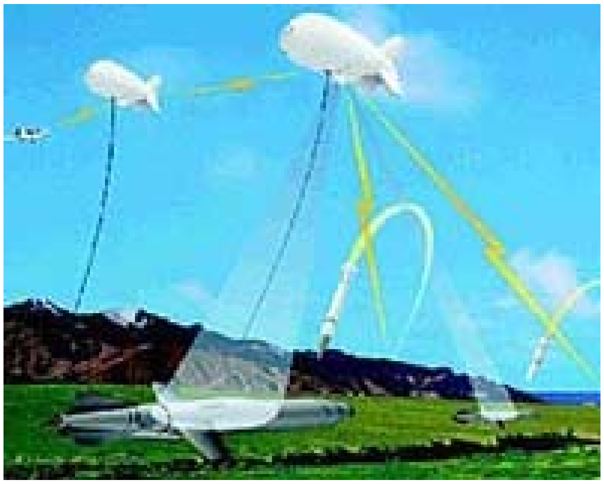


Figure 22. JLENS updated system (From: Staff Writers, 2008)

III. PROBLEM DEFINITION PHASE

A. OVERVIEW

As discussed in Chapter I, the systems decision process used in this research consists of four major phases that are iterative in nature and assist in organizing the problem: problem definition, solution design, decision making, and solution implementation. The first phase, problem definition, consists of three key components: conducting stakeholder analysis, performing functional analysis, and constructing a value model. The problem definition phase does not focus on solutions and is an iterative in nature. At the end of this phase, a clearly defined problem statement emerges that meets the approval of the stakeholders, along with:

> Screening criteria that can be used to ensure solutions meet the minimum requirements of the system before the solutions are fully designed, modeled and analyzed and an initial quantitative methodology for evaluating how well solutions meet the values of stakeholders in solving the correct problem. (Parnell, Driscoll, & Henderson, 2008, p. 266)

B. STAKEHOLDER ANALYSIS

The first step in the problem definition phase is identifying the relevant stakeholders and eliciting their input regarding their needs or desires regarding the problem and system being addressed. Stakeholders are individuals who have a vested interest in the problem and its solution, and can be owners, users, managers, customers, clients, administrators, maintainers, and regulators of the system. These stakeholders often have varying perspectives on desired system functions, end states, and requirements. In order to assess the needs of the stakeholders, stakeholder interviews and surveys were used to assist in the identification of the key issues. The following are important stakeholders for this problem and a summary of their input to the systems engineering process.

1. Clients

a. Department of Defense (DoD)

The United States DoD is currently a recognized expert in the field of IEDs and C-IED technology, due to its extensive research and technology developments. The United States military is currently funding and training personnel in efforts to defeat IEDs, conduct academic and field research, development and testing of sensor systems, and relooking tactics, techniques, and procedures in C-IED.

b. The Joint Improvised Explosive Device Defeat Organization (JIEDDO)

JIEDDO's mission is to focus (lead, advocate, coordinate) all DoD actions in support of combatant commanders' and their respective joint task forces' efforts to defeat IEDs as weapons of strategic influence (JIEDDO, 2008). Their research is broken down into three main categories: attack the network by preventing the emplacement of the IED by attacking enemy vulnerabilities at multiple points in the IED system; defeating the device by defeating the IED once it is emplaced; and training the force by facilitating the establishment and growth of coalition and partner nation C-IED capabilities.

2. Users

a. Brigade and Battalion Commanders

These commanders are responsible for executing their assigned missions within their area of operations. These commanders must have SA during all phases of their deployments and each tactical operation to which they commit troops. Ideally, commanders at this level will have access to up-to-date imagery, with detailed intelligence analysis at their fingertips. Various lieutenant colonels, battalion commanders, and brigade staff officers were contacted via secure internet protocol router network (SIPRNET) during their deployments in the summer and fall of 2008. These

individuals provided real-time desires and assisted in the development of the top-level system requirements and MOPs, which were incorporated into a survey for staff officer and company-grade officer feedback.

b. Staff Officers and Company-grade Leadership

These individuals are responsible for preparing intelligence reports for higher commanders, executing specific tactical missions, and briefing Soldiers on current enemy situations. These officers made up the majority of those surveyed, and were large contributors to the development and weighting of the MOPs as well as the analysis of alternatives.

c. The Individual Soldier

The Soldier on the ground is responsible for executing specified missions from his company leadership. These Soldiers are impacted the most by the decisions made by higher leadership based on the human intelligence, unmanned sensors, ground cameras, and robotics. Since there were no Army enlisted personnel at the Naval Postgraduate School (NPS) at the time the survey was administered, their input is missing from this analysis.

d. Explosive Ordinance Disposal (EOD)

EOD teams have the ability to locate the exact position of a suspected IED, identify and classify it, conduct render safe procedures, and provide safe transport and final disposal of the IED (Headquarters, Department of the Army, 2001). Many techniques and technologies exist for EOD utilization and selection of a technique often depends on the proximity of the IED to people or critical facilities. IEDs that are located on busy road or near personnel are handled very differently from those in remote locations.

3. Analysts

The C-IED fight is an area of high priority for our nation and numerous organizations are currently involved in research. JIEDDO (through research at NPS and

other academic institutions), the research and development corporation RAND, the defense advanced research projects agency (DARPA), DoD military intelligence units, the Central Intelligence Agency (CIA), and the National Security Agency (NSA) are just a few of the organizations conducting research in unmanned sensors, and C-IED operations.

4. Others

There are a number of people who are impacted by IEDs. Host nation civilians, the media, military family members, members of the Senate and Congress, and American taxpayers all have a vested interest in the improvement of SA in the C-IED fight.

5. Key Stakeholders

Direct stakeholder input from two sources helped to frame the problem, and ensure the tactical and technical needs were being addressed. The tactical contributors provided information via email interviews and as survey respondents, and consisted of the Army officers listed in Appendix B. The technical opinions were gathered from various interviews with members of sensor technology companies and several research development teams during the Defeating Improvised Devices Meeting held in San Diego on 21-22 October 2008.

C. FUNCTIONAL ANALYSIS

Functional analysis is the process of identifying the system functions and interfaces required to meet the system's performance objectives. It is imperative to identify all of the system functions and interfaces, or the desired end state may not be met.

1. Operational Scenario

In order to perform a functional analysis, an operational scenario must be defined in which to evaluate the problem. While the intent of this research is not to propose a specific, detailed scenario to provide context for systems design, we do identify an important category of scenarios for consideration.

A common operational scenario faced in the C-IED environment is distinguishing IEDs from garbage on the road or detecting disturbed soil. The Marine Corps Operational Test and Evaluation Activity (MCOTEA) has developed numerous variations based on this operational scenario. One variation, shown in Figure 23, focuses on monitoring friendly and enemy activity, finding emplaced RCIEDs, and recognizing disturbed soil patterns within one unit's area of operations. In this scenario, the unit is concerned with monitoring an AO that contains approximately 20 miles of paved roads traveling outside of an urban environment. Within the unit's assigned area of operations there are main supply routes (MSR), or lines of communications (LOCs), which connect various forward operating bases (FOBs), outposts (OPs), or local towns. These MSRs and LOCs are traveled numerous times a day by various types of military and civilian vehicles as well as coalition foot patrols and the local populace. These routes are located outside of a large urban area and are alongside host-nation homes, gardens, or fields. Unmanned sensor operators are tasked with observing, detecting, identifying, and classifying emplaced RCIEDs or disturbed soil along these routes, based on the suspected RCIED characteristics and soil patterns.

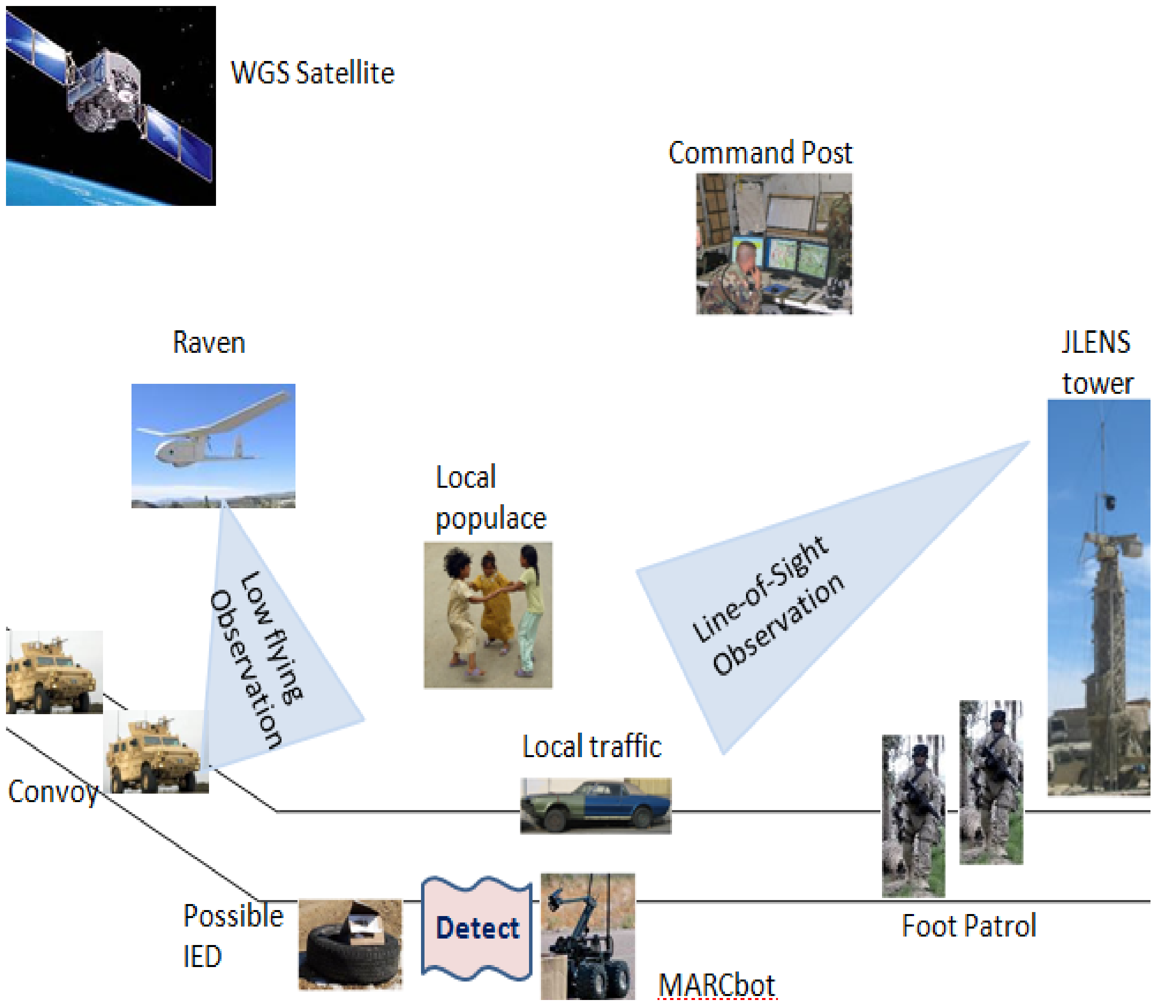


Figure 23. C-IED operational scenario

2. Functional Flow

a. Enemy Decision Cycle

Unmanned sensor technology may be of assistance in detecting terrorists during numerous phases of the operation. Sensors can track individuals during reconnaissance missions, rehearsals, delivery and emplacement of an IED, observation of the explosion, and during their escape. The following functional flow diagram, shown in Figure 24, visually organizes the steps a terrorist must take in order to successfully emplace an IED.

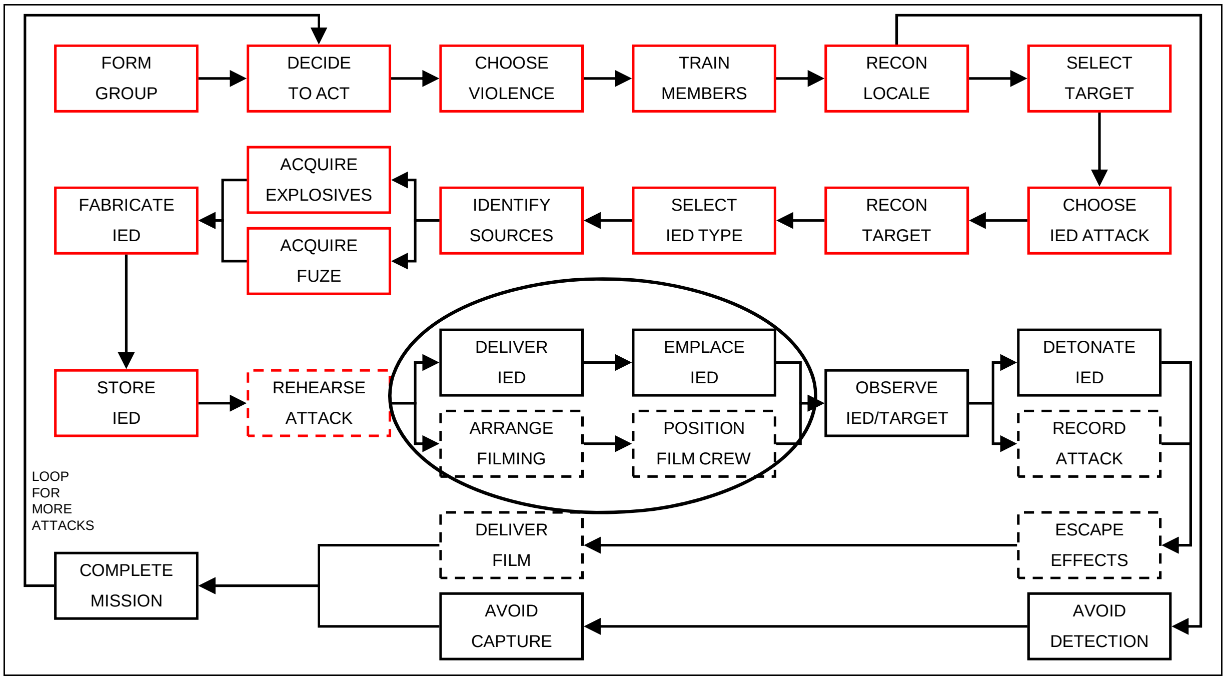


Figure 24. Functional flow diagram of a terrorist attack
(After: Diagram provided by Dr. Robert Harney, NPS, 2008)

A terrorist is most vulnerable to detection, identification, and capture during the *rehearsal of the attack* through *escape effects* and primarily in the highlighted portion above, while *delivering* and *emplacing* the IED. This enemy decision cycle functional flow diagram displays the need for a friendly system that can:

- Observe a sector.
- Detect suspicious activity.
- Provide decision makers with usable information that allows for quick and decisive actions.

b. Friendly Forces Analysis

A functional flow diagram for friendly forces' actions in a C-IED mission and its utilization of unmanned sensors is shown in Figure 25. A UAS C-IED flight pattern, or unmanned sensor, emplacement begins with the mission receipt and the deployment of assets to an assigned area of operation. Once the assets are emplaced,

search parameters are inputted to begin gathering data. The *observation phase* begins once the sensor begins its sector search and includes the processing of the data. The data is either sent simultaneously to the user and analysts, or stored on board for downloading at a later time. Once data is received by the analysts, the data is fused and analyzed. While this fusion and analysis are time consuming, *the detection phase* occurs as objects or activities are identified and classified throughout the process. Objects of interest or suspicious activities are annotated and verified, if possible, before being transmitted to the user. Once the data is received by the user, the *battle management phase* begins, as the user utilizes this data to establish a COP and conduct analysis. At this point, a decision point is reached where the user can choose to take action or can request subsequent imagery. This research focuses on the circled portion of Figure 25.

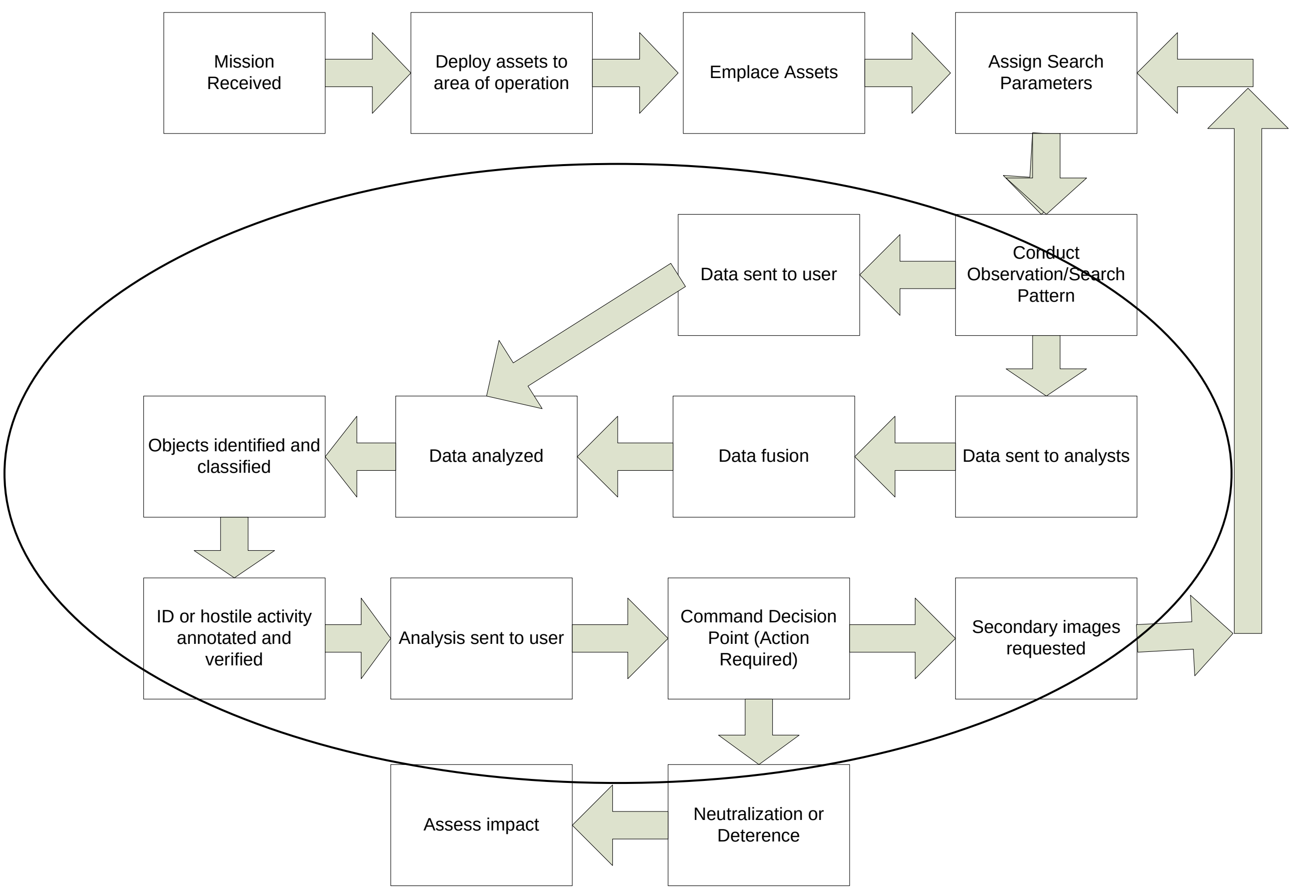


Figure 25. Friendly forces functional flow diagram

3. Input-Output Model

An input-output model assists in the development of the functional hierarchy and describes the controllable and uncontrollable inputs to a system and the intended outputs and by-products of the system. The input-out model, shown in Figure 26, helped to identify and categorize the inputs and outputs for the desired C-IED system, which focuses on providing improved SA. The controllable inputs are those that can be measured, calculated, built, or compiled by the designers in the developmental and test and evaluation phases. These aspects were categorized into physical, human, informational, and economical. The physical inputs included sensor characteristics (weight, dimensions, speed, resolution, datalinks, payload, etc.), and surveillance time. The human inputs included TTPs and doctrine, organization, training, material, leadership and education, personnel, and facilities (DOTMLPF). In fact, the combination of physical and human inputs reflects that the potential alternatives have both material and nonmaterial components, which is discussed further in Chapter IV.

The informational inputs included the technical manuals available for training and maintenance of equipment, information gathered from ongoing operations, and information received from psychological operations. The economic inputs include the cost for acquisition and maintenance of the system.

The uncontrollable inputs are those aspects that are beyond the control of the designers and were categorized into physical, human, and informational. Physical inputs include environmental conditions including the weather and time of day; human inputs include enemy TTPs, target selection, and the demographics of the local populace; and informational inputs include the type of IED the enemy chooses to emplace.

The intended outputs of a system are those which are essential to providing improved SA to friendly forces that may encounter IEDs. These outputs include the correct detection, classification, identification and countering of the IED, rapid transmission of imagery across the battlefield, and an improved COP and SA for commanders and the individual Soldier. Though the system of systems is designed to counter IEDs, several unintended outputs will inevitably result and are referred to as by-products. The positive by-products of the system include fewer casualties and

incidents, and better relations with the local populace. The potentially negative by-products of the system include false detections, identifications or classifications, the enemy's development of better IEDs and technology, and the enemy's improvement of organization and recruiting.

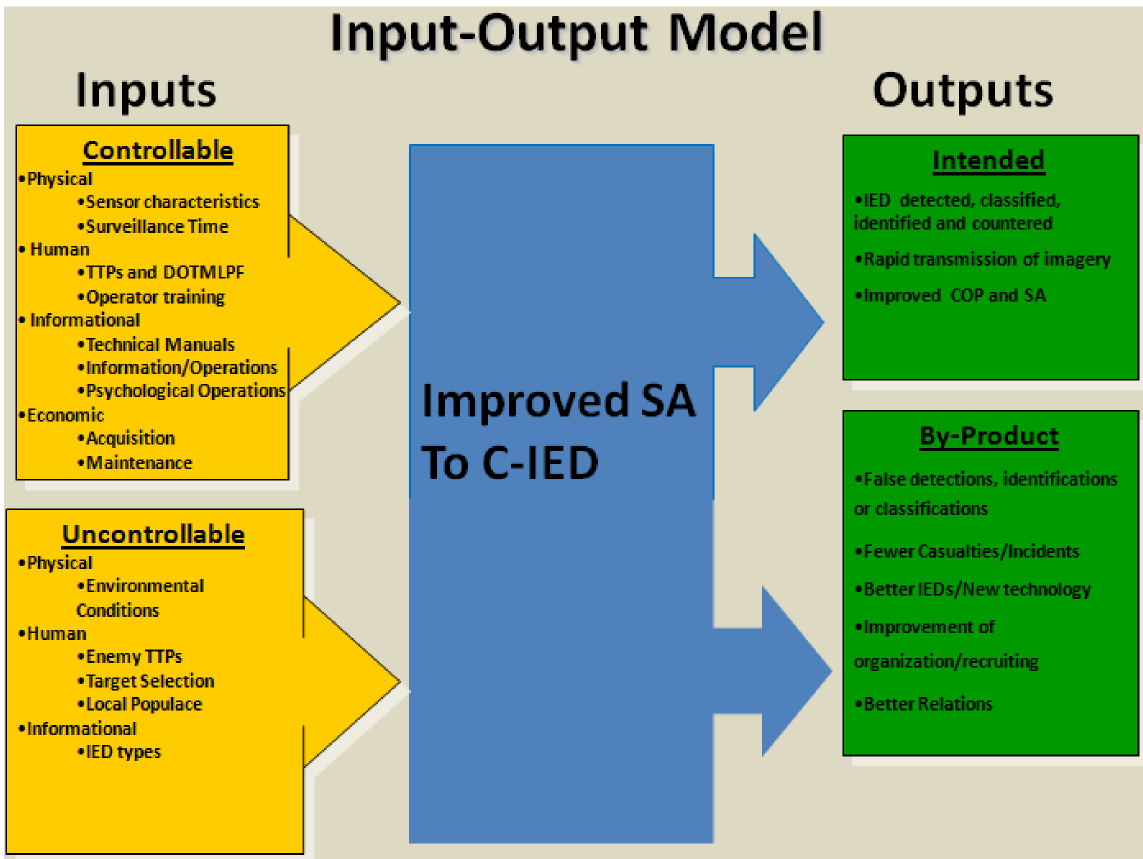


Figure 26. Input-output model

4. Objectives Hierarchy

The objectives hierarchy serves as the foundation for the assessment of the candidate solution designs (Parnell, Driscoll, & Henderson, 2008). It typically begins with a single, overarching, top-level objective from which subobjectives, or functions, derive. The top-level objective is also the revised problem statement, based on the development of the functional flow diagram, input-output model, as well as input from stakeholders.

The revised problem statement is as follows: Design a system that, through the use of unmanned sensors, provides effective and efficient SA to the commander in a C-IED scenario. By effective, the system must maximize the ability to process sensor imagery, detect, classify, identify, and counter IEDs. To be efficient, the system must address important characteristics of operational suitability and survivability. Thus, providing SA, maximizing operational suitability, and maximizing Soldier survivability are the top-level objectives in the effective employment of unmanned sensors in C-IED. The top level objectives of the objectives hierarchy are shown in Figure 27.

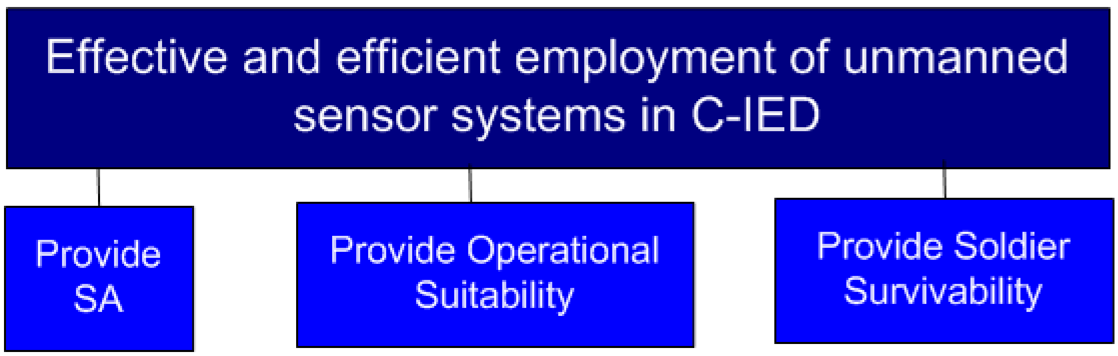


Figure 27. Top-level objectives of objectives hierarchy

5. Situational Awareness (SA) Defined

While Operational Suitability and Soldier Survivability have clearly defined objectives and are widely used in military test and evaluation, the role of providing SA in the effective employment of unmanned sensor systems in C-IED needs further defining. We propose that a complete and useful description of SA in this circumstance should be based on a sensible, generic theoretical model of SA and then fully built through the inclusion of military concerns, such as the commander's priorities.

a. A Generic SA Model

SA can be difficult to measure and, at times, even harder to establish. While specific definitions and applications for SA have been developed for military problems, broader visions and models of SA have also been proposed. For example, the

model in Figure 28, developed by Dr. Mica Endsley, presents three levels in the creation of SA: perception (level 1), comprehension (level 2), and projection (level 3). Perception includes perceiving the status, attributes, and dynamics of the elements within a given environment. Achieving level 1, or perception, includes the process of monitoring, cue detection, and recognition. Perception leads to an awareness of multiple situational elements including objects, events, environmental factors, people, systems, and their current locations, modes, or actions. Comprehension (level 2) is pattern recognition, interpretation, and evaluation. Achieving level 2 involves a synthesis of disjointed level 1 SA elements through the process of pattern recognition, interpretation, and evaluation. This level requires the integration of this information in order to understand how it may impact goals and objects. Level 2 involves developing a comprehensive picture of the world or, in this research, a COP. Projection (level 3) involves the ability to predict the future actions of elements in the environment. This is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation through levels 1 and 2, and then extrapolating this information forward in time to determine how it will affect future states of the operational environment (Endsley, 1995).

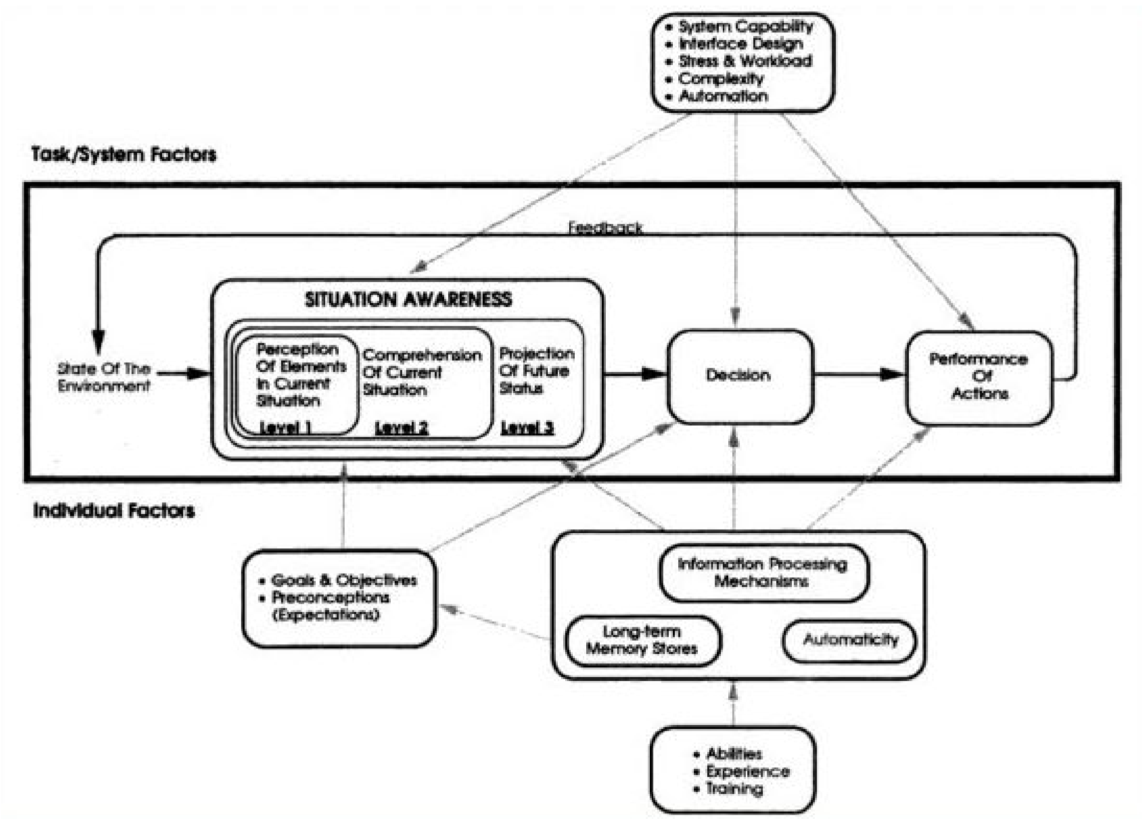


Figure 28. Model of SA in decision making (From: Endsley, 1995)

b. Army Approach to SA

Commanders and their staffs develop information priorities in order to make better decisions. The general term for this essential information is Commanders Critical Information Requirements (CCIR), which is defined as:

> Comprehensive list of information requirements identified by the commander as being critical in facilitating timely information management and the decision making progress that affect successful mission accomplishment. The three key subcomponents are the essential elements of friendly information (EEFI), friend force information requirements (FFIRs), and priority intelligence requirements (PIR). (Headquarters, Department of the Army, 2004, p. 1-34)

The commander is often forced to make decisions with an incomplete view of the battlefield and selects CCIRs that assist in information gain. There are three types of CCIR: enemy or threat, friendly, and environmental. The most important component of CCIR is PIR, which is defined as:

> Those intelligent requirements about the enemy and environment for which a commander has an anticipated and stated priority in his task of planning and decision-making. They are often associated with a decision that will critically affect the overall success of the command's mission. (Headquarters, Department of the Army, 2004, p. 1-150)

The relationship between information, CCIRs, and command decision points (DP) is illustrated in Figure 29.

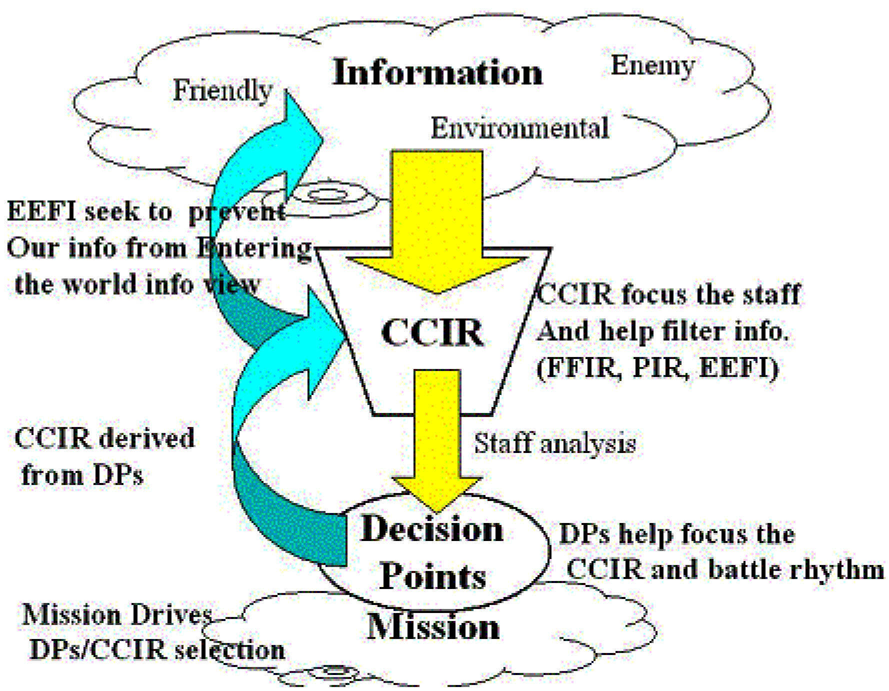


Figure 29. Commander decision point flow (From: Ptak, Webster, & Wilson, 2003)

Information gathered across the battlefield that answers a commander's CCIRs assists in effective decision making. SA helps commanders make critical decisions using information based more on facts than assumptions, and also reduces the risk involved in decision making.

There are various techniques that are often used to measure SA. Military professionals commonly describe operations in terms of Mission, Enemy, Terrain, Troops, and Time Available (METT-T) in order to plan and execute operations (Headquarters, Department of the Army, 1997). METT-T provides a good breakdown of a commander's desired informational elements and provides a start point for determining what factors must be known in order to establish SA. These elements are ever-changing, and each operational scenario will have its own unique considerations. However, in the C-IED fight, commanders are interested in the location of already emplaced IEDs as well as the ability to track the enemy network involved in the IED process. The enemy is a key component of SA in any operational environment, and in the C-IED fight, the IED and the network are the strategic enemies of choice. SA also includes observing the battlespace, processing input from those observations, and developing an understanding of the environment, which includes both friendly actions and threat activity. SA in the C-IED fight includes the ability to observe the battlefield, process imagery, and understand the operational environment.

c. Linking Army SA with Endsley Model

Endsley's model provides an excellent framework for describing specific military concerns regarding SA. Applying Endsley's model to Army operations and Army SA focus, it is reasonable to state that achieving level 1 SA in the C-IED fight includes the ability to observe the battlefield utilizing human intelligence (HUMINT) and signal intelligence (SIGINT). SIGINT must be processed into quality and valuable information prior to being of use to a commander. Additionally, achieving level 2 SA in the C-IED fight includes the ability to monitor and recognize convoys, friendly, neutral and enemy forces, as well as environmental factors. Commanders need to be able to determine pattern recognition, and see disturbed soil patches. Ideally, multiple Soldiers on the ground, commanders in tactical operation centers (TOC), and data analysts would

have access to the same imagery and be able to determine the attributes and dynamics of hostile events and forces. Figure 30 shows clear linkage between Endsley's model and achieving SA in the C-IED fight. A more detailed discussion of the components of the Activity Diagram, and how they relate to the objectives hierarchy, is found below.

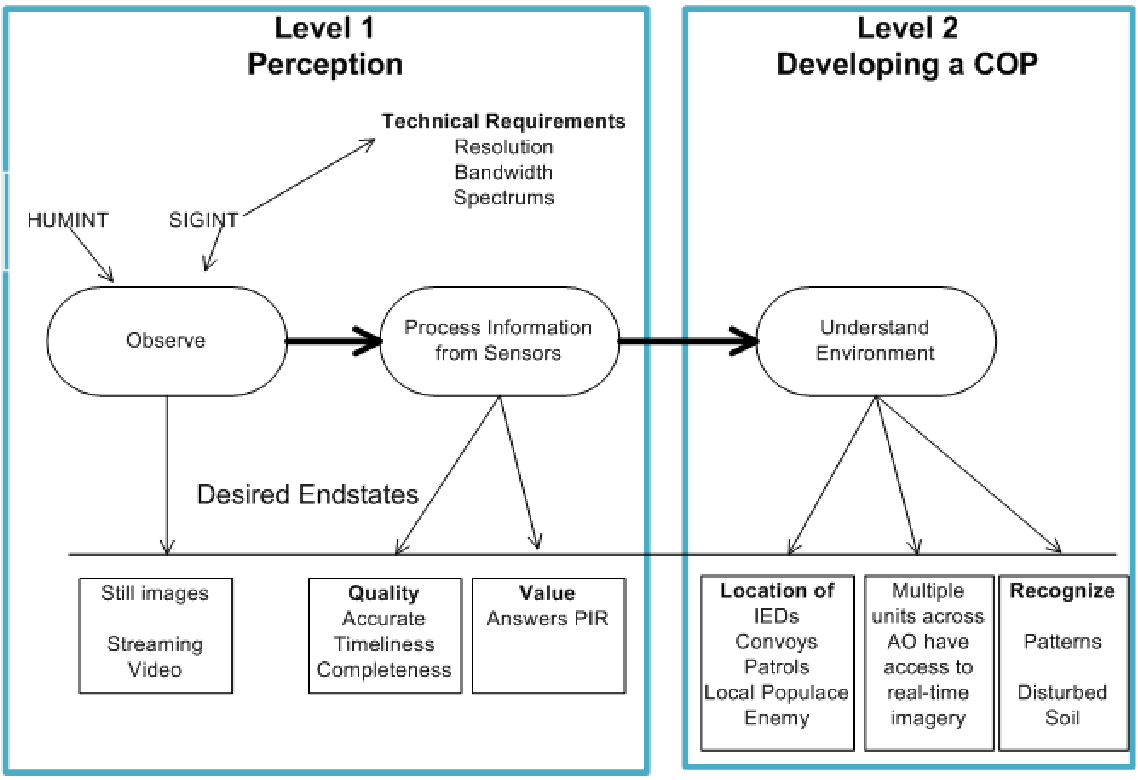


Figure 30. Activity diagram for achieving SA in C-IED (After: Endsley, 1995)

D. VALUE MODEL

Value modeling provides "an initial methodology for evaluating candidate solutions" (Parnell, Driscoll, & Henderson, 2008, p. 289). Value modeling consists of both qualitative and quantitative models, which assist in evaluating the future value of the implemented solution to the problem.

1. Qualitative Value Model

The qualitative value model strives to present the most important functions and objectives for the system, and is more important than the quantitative model because it reflects the key stakeholder values regarding the system (Parnell, Driscoll, & Henderson, 2008).

a. Provide SA

Utilizing the activity diagram above, the top level functions for providing SA are: *observe, process information from sensors,* and *understand the environment.* While there may be additional components of SA, the ability to observe one’s area of operation, process sensor imagery, and understand the operating environment serve as key components in information gain, establishing a COP, and generating SA.

Observation of the battlefield is achieved via HUMINT and SIGINT. Squads on patrol, Soldier interaction with the local populace, interrogation of detainees, and informants are all forms of HUMINT. While HUMINT is an important component of observation on the battlefield, this research focuses solely on the utilization of SIGINT. Manned and unmanned sensors are the key components of SIGINT and provide a commander either still imagery or streaming video of designated target or observation areas. Sensors have varying payloads, resolution capabilities, bandwidth restrictions, and available spectrums in which to perform surveillance operations. A sensor’s image quality is a function of the bandwidth available from satellites, the image resolution, and the display resolution (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008). Digital image resolution and display resolution is measured by the pixel count with a set of two positive integers; the first number is the number of pixel columns (width) and the second is the number of pixel rows (height) (Kerlin, 2009). A pixel is one of the many tiny dots that make up the representation of a picture in a computer's memory. Larger payloads on sensor systems mean more capability to carry a variety of equipment. Therefore, the MOPs for the observe function are:

- Quality of imagery: bandwidth available from satellites (higher is better), the image resolution (higher pixel count is better), and the display resolution (higher pixel count is better).
- Surveillance coverage: percentage of roadway in AO covered in a 24-hour period (higher is better).
- Sensor payload capacity in pounds (higher is better).

The data received from unmanned systems must be processed in order to provide commanders with useful information. Information consists of two critical attributes: value and quality (Perry, 2000). Information has value if “it informs the commander and thereby adds to his knowledge of the combat situation” (Perry, 2000, p. 3). Information has value in providing SA if it answers or assists in answering CCIRs. Information quality consists of three components: accuracy, timeliness, and completeness (Perry, 2000). Therefore, when providing SA in combat operations, it is imperative to utilize functions that contribute to providing a commander with both valuable and quality information.

Accurate and complete information in combat operations is enhanced by unmanned sensors when data fusion occurs to combine all available information (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008). Data fusion is the process of putting together information obtained from many heterogeneous sensors, on many platforms, into a single composite picture of the environment. Emerging technology allows for imagery and videos to be fused utilizing meta-data tagging, which are tags describing the data to enable discovery, and include time, location, classification, and sensor calibration. Tags allow data gathered from separate sensors to be combined in a meaningful way. Ideally, meta-data tagging should be done at the sensor, rather than having analysts who receive the data tag it. While the meta-data tagging standards and processes are evolving, adoption of these standards in sensor systems has been slow.

Accurate and complete information is of no use to the commander if it arrives too late. The speed in which information is transmitted, processed, and analyzed

greatly impacts a commander's ability to act effectively and decisively on the battlefield. Therefore, the MOPs for the process function are:

- Number of sensors with meta-data tagging capability (more is better).
- Processing time: the sum of the time it takes an unmanned sensor to transmit imagery or video and the time it takes the data to be processed, analyzed, and sent to the user (less is better).

Commanders need useful and valuable information in order to understand their environment, which includes detecting IEDs, enemy activity, friendly forces, local activity, as well as recognize disturbed soil or track insurgent's activity patterns. Unmanned sensors can be used to identify and classify potential IEDs or investigate disturbed soil to negate risk to personnel. Sensor systems that provide real-time imagery for all units operating within an area of operations greatly enhances shared COP.

Detection is the "actual confirmation of an obstacle" and phase of an operation where potential IEDs are identified for further classification and identification (Headquarters, Department of the Army, 2000, p. C1). There are four primary means of detecting an obstacle: visual, physical, electronic, and mechanical (Headquarters, Department of the Army, 2000). Unmanned sensors conduct visual sector searches of a unit's area of operations, electronically locate, and mark possible IEDs. Visual sector searches are intended to increase the amount of surveillance of the routes in the AO and increase the number of IEDs detected along the route. The effectiveness of electronically locating and marking IEDs is determined by the probability of detection and probability of false detection (Headquarters, Department of the Army, 1998).

In order for an IED to be detected by a sensor, it must contain certain attributes or characteristics pertaining to IEDs (size, shape, etc.) that define it as a potential IED. Army Field Manual (FM) 3-34.119, *Improvised Explosive Device Defeat*, warns that "specific identification features for IEDs are ever-changing based on the capabilities and available resources of the enemy" (p. 4-1). The manual states that IEDs share a common set of components: the main charge, initiating system, and casing. Attributes of a main charge vary from military munitions (mortar or tank rounds) to commercial explosives such as trinitrotoluene (TNT). Initiating systems vary from

simple hard wire to remote control units for garage door openers or toys; however, the system will almost always consist of a blasting cap. Casings for IEDs range in size and are used to help hide the IED from plain sight. FM 3-34.119 states that the primary indication of an IED is a change in the environment and lists the following as possible roadside IED indicators:

- Unusual behavior patterns or changes in community patterns.
- Vehicles following a convoy for a long distance and then pulling to the roadside.
- Personnel using overpasses.
- Signals from vehicles or bystanders.
- People videotaping ordinary activities or military actions.
- Suspicious objects.
- Metallic objects, such as soda cans and cylinders.
- Colors that seem out of place, such as freshly disturbed dirt, concrete that does not match the surrounding areas, colored detonating cord, or other exposed parts of an IED.
- Markers by the side of the road, such as tires, rock piles, ribbon or tape that may identify an IED location to the local population or serve as an aiming reference.
- New or out-of-place objects in an environment, such as dirt piles, construction, dead animals, or trash.
- Graffiti symbols or writings on buildings.
- Signs that are newly erected or seem out of place.
- Obstacles in the roadway to channel convoys.
- Exposed antennas, detonating cord, wires, or ordinance.
- Wires laid out in plain sight.

Pattern recognition and being able to compare historical and real-time imagery are key components in detecting an IED indicator or attribute. Pattern recognition assists the commander in identifying suspicious behavior of the local

populace and monitoring traffic patterns. Comparing historical and real-time imagery allows analysts to quickly note areas where the ground has been disturbed, roadside debris, or markers on the side of the road.

Intelligence analysts may convert these indicators into IED attributes based off of the commander's CCIR or PIR. These specified attributes can then be used in a mathematical model, Bayes' theorem, to determine a sensor's probability of detection or probability of false detection. Bayes' theorem relates the conditional and marginal probabilities of two random events and is then used to compute posterior probabilities (Ragsdale, 2007). In the event of trying to detect IEDs through the use of sensor, the sensor's probability of detection is conditional on the marginal probability of an IED attribute being present or not present. For this calculation to be of use to the analyst, it must be based on real data, as the specific conditional probabilities must be determined through the use of historical data and analysis. The probabilities of detection and false detection are calculated for an entire unmanned sensor system—not for a single sensor.

- Probability of Detection: probability that sensor system can make the proper determination that an object has attributes of an IED (higher is better):

Pr(sensor detects attribute) = Pr(sensor detects attribute │attribute present) * Pr(attribute present)+ Pr(sensor detects attribute │attribute not present)* Pr(attribute not present)

- Probability of False Detection: probability that the system makes the wrong determination as to the presence of an IED attribute (lower is better):

Pr (sensor not detect attribute)=Pr(sensor not detect attribute│attribute present)* Pr(attribute present) + Pr(sensor not detect attribute)│(attribute not present)* Pr(attribute not present)

Identification and classification of an IED is when a possible IED has been detected and is further investigated to determine the identification of the IED. While the detection of the IED may be done by passive surveillance (UAS or cameras), active

surveillance (UGV, or Soldier reports) or a combination of both, identification and classification is primarily done by active surveillance measures, specifically EOD or UGVs (Headquarters, Department of the Army, 1998). The probabilities of identification and false identification are also calculated using Bayes theorem and are conditional on the probability of an IED being present. Again, this calculation must be based on real data, as the specific conditional probabilities must be determined through the use of historical data and analysis. The probabilities of identification and false identification are calculated for an entire unmanned sensor system—not for a single sensor:

- Probability of Identification: the probability that a system can make the proper identification and classification of the IED (higher is better):

Pr (sensor identifies IED) = Pr(sensor identifies IED│IED present) * Pr(IED present)+ Pr(sensor identifies IED│IED not present)* Pr(IED not present)

- Probability of False Identification: probability that the system makes the wrong identification and classification of the IED (lower is better):

Pr (sensor not identify IED)=Pr(sensor not identify IED│IED present)* Pr(IED present) + Pr(sensor not identify IED)│(IED not present) * Pr(IED not present)

Understanding the environment can also be enhanced by the availability of real-time imagery for all units operating within the area of operations (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008). Situational awareness across the battlefield is greatly enhanced if commanders operating out of TOCs are able to speak with convoys or Soldiers on foot patrol, while accessing real-time shared imagery. Numerous units or field elements with access to real-time

video feed or high-resolution imagery allows for collaborative efforts across the battlefield in dealing with a multitude of situations, and contributes to the completeness of information.

- Number of units with real-time imagery (higher is better)

b. Provide Operational Suitability

Operational suitability is not intended as a physical attribute of the system, or what the system does, but instead measures the characteristics of the system. Operational suitability is the degree to which a system can be satisfactorily placed in field use with respect to reliability, availability, and maintainability (RAM), supportability, human systems integration (HSI), and interoperability.

This research focuses on the impact of reliability and maintainability in the emplacement of unmanned sensor systems in the C-IED fight. These two components were selected because they are important considerations from both the system and individual Soldier perspective. Equipment utilized in combat must be able to perform at a high performance level for a sustained period of time. When new or updated systems are introduced without sufficient operational testing or with an expedited time line, military maintenance capabilities are limited.

The first component of RAM is reliability, which is the duration or probability of failure-free performance under stated conditions (Blanchard & Fabrycky, 2006). Mission reliability is the probability of no critical failure under specified mission conditions for the overall system of sensors and communications links. There are numerous ways to characterize the reliability of a system, including failure mode effects analysis, fault trees, and reliability block diagrams (RBD). An RBD is

> A graphical representation of the reliability dependence of a system on its components. It is a directed, acyclic graph. Each path through the graph represents a subset of system components, and if the components in that path are operational, the system is operational. Component lives are usually assumed to be independent in a RBD. Simple topologies include a series system, a parallel system, a *k* of *n* system, and combinations of these. (Schrady & Olwell, 2002, ref p. 3-6)

An RBD for an alternative with one satellite system, one UAS, one UGV, and one stationary camera platform is best constructed using a series system and is shown in Figure 31.

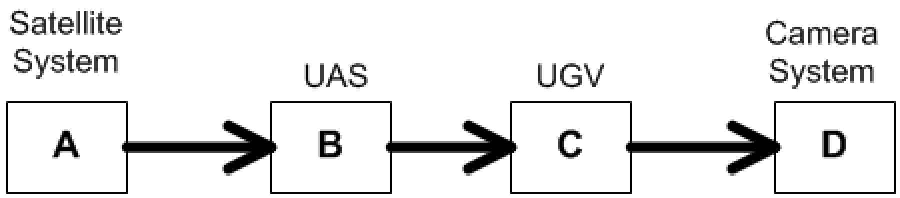


Figure 31. RBD for unmanned sensors in series

In a series system, if any block fails the entire system fails. This type of RBD was selected because this research focuses on providing SA utilizing an entire unmanned sensor system, not just a single sensor. While imagery and video-feeds may be available utilizing just one sensor platform, the system would not be operating as intended and in fact would be severely degraded. The following definitions are used in order to calculate the overall system reliability for this series system:

R(A): is the reliability of the satellite system

R(B): is the reliability of the UAS

R(C): is the reliability of the UGV

R(D): is the reliability of the camera system

The system's reliability, at time t, is calculated:

$R_S=R(A)*R(B)*R(C)*R(D)$ (the higher the better)

Maintainability is the ability of an item to be retained in, or restored to, a specific condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources at each prescribed level of maintenance and repair.

- Percentage of appropriate maintenance personnel trained to repair equipment (higher is better).

- Percentage of repair parts available in unit level logistics system (higher is better.)

c. Provide Soldier Survivability

In general, Soldier survivability consists of six key components: reduce fratricide, reduce detectability of the Soldier, reduce probability of being attacked, minimize damage, minimize injury, and reduce physical and mental fatigue (Payan & Zigler, 2008). It terms of providing SA in the C-IED fight utilizing unmanned sensors, the key component of maximizing Soldier survivability is reducing physical and mental fatigue on the Soldier. Reducing physical and mental fatigue is measured by the physical, cognitive, and workload constraints placed on the Soldier by the system (Payan & Zigler, 2008).

- Reduce training time (less is better).
- Reduce physical workload (less is better).

The objectives hierarchy, shown in Figure 32, shows the relationship of the three top-level objectives and their subobjectives, and serves as the foundation for assessing the selected alternatives.

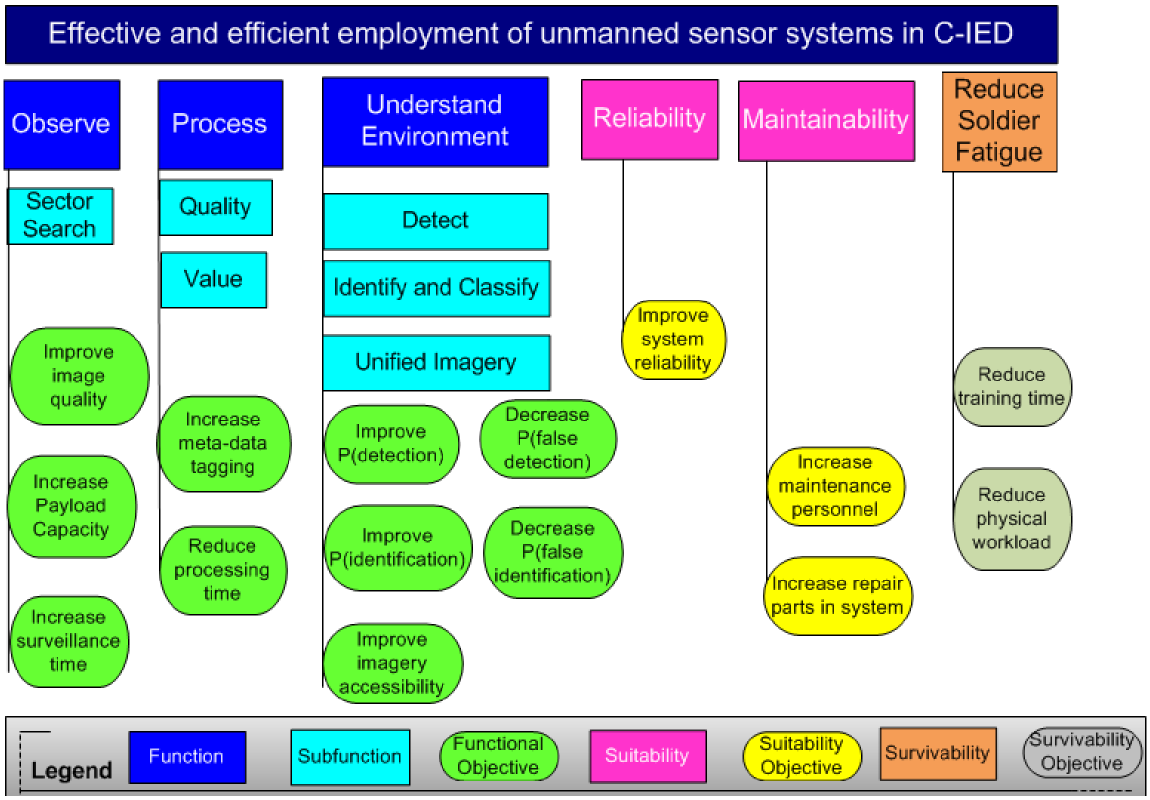


Figure 32. Qualitative value model

2. Quantitative Value Model

Quantitative value modeling "allows us to determine how well candidate solutions to our systems decision problem attain the stakeholder values" (Parnell, Driscoll, & Henderson, 2008, p. 294). More specifically, applying value functions (or utility functions) to metrics provides both a means of essentially normalizing quantitative data so that different units of measure are irrelevant, and a way of clearly showing relative value of all possible outcomes for each metric.

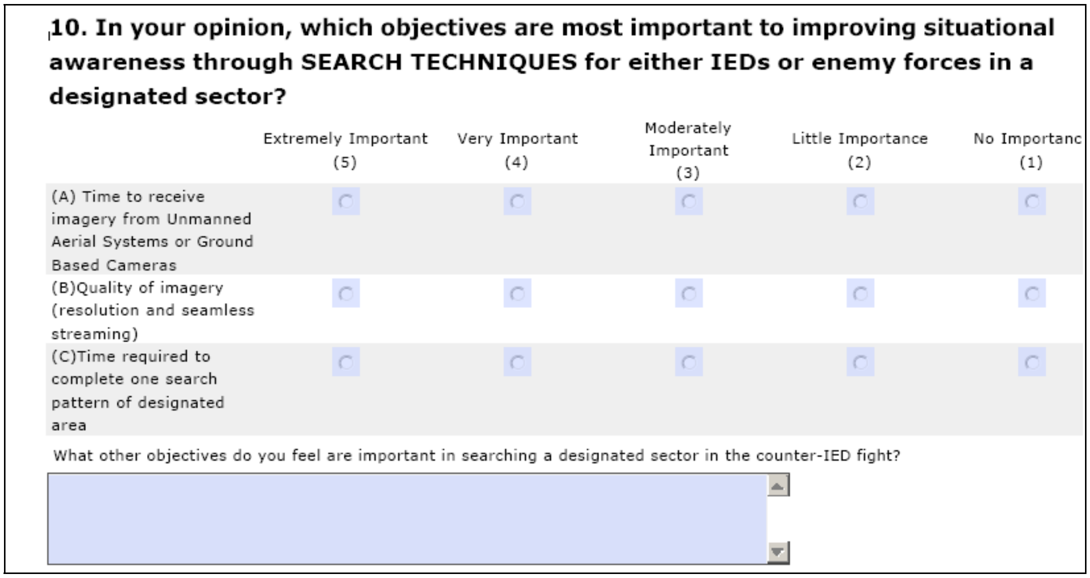
a. Survey

A survey was developed to update and possibly improve the proposed functions, objectives, and metrics. This survey was designed to see if there were key pieces missing in the analysis, possibly establish weights for the proposed MOPs for use in modeling, and to see what the war-fighter felt about the utilization of each subset of

unmanned sensors in the C-IED fight. The intended audience was active duty Army officers currently attending the Naval Postgraduate School in the winter of 2009, with deployment experience defined as six months or more in either Iraq or Afghanistan since 2003.

There was very little demographic information obtained from the respondents; however, in order to ensure the survey sample represented the desired population of Army officers who have deployed, the respondents were asked to provide how many times they had deployed (for at least six months) to either Iraq or Afghanistan since 2003. There were follow-on questions to determine at what level the respondent worked, and what type of unit they were in as well as the position they held for each deployment they participated in. No other specific demographic information was collected; however, a respondent's rank could be determined based on some of the positions they may have held.

Upon establishing the deployment information, respondents were asked to provide their level of agreement with the Army's definition of SA, their opinions on the proposed functions, objectives, and MOPs in providing SA in the C-IED fight, thoughts on what unmanned sensor systems they felt were most effective or ineffective in their C-IED experiences, as well as an opportunity to provide open-ended feedback. Probably the most significant input from the respondents involved their opinions of the value of the various metrics under consideration. This input was key to determining the value functions described in the following section. The survey is enclosed in Appendix A, and a snapshot of the survey is shown in Figure 33.



10. In your opinion, which objectives are most important to improving situational awareness through SEARCH TECHNIQUES for either IEDs or enemy forces in a designated sector?

	Extremely Important (5)	Very Important (4)	Moderately Important (3)	Little Importance (2)	No Importanc (1)
(A) Time to receive imagery from Unmanned Aerial Systems or Ground Based Cameras					
(B)Quality of imagery (resolution and seamless streaming)					
(C)Time required to complete one search pattern of designated area					

What other objectives do you feel are important in searching a designated sector in the counter-IED fight?

Figure 33. Example survey question

Of the 84 students who received an invitation to take part in the survey, 28 completed the survey, 2 partially completed the survey, and 54 did not participate. Of the 28 students who completed the survey, 3 had never deployed, 14 deployed once, 9 deployed twice, and 2 had deployed 3 or more times. None of the students had worked on a Divisional Staff, although 1 student worked on Central Command (CENTCOM) staff and another was a part of III Corps Headquarters. The majority of students who deployed worked in a BCT (64%) in some capacity—either on Brigade Staff (17%), Battalion Staff (14%), or as Company Commanders (33%). This appeared to be a representative sample of the desired population—officers that have deployed in a BCT. There were also students who had deployed as members of small military transition teams (MITT) or as part of an EOD detachment.

b. Generating Value Functions for Each Metric or MOP

The responses from the survey, stakeholder input, and analysis were used to assist in the development of value measure functions. The value function for each metric is described below, with a chart displaying the weights used and a graph that shows the shape of each value function.

3. Quality of Imagery

Quality of imagery is measured by the bandwidth available from satellites with larger bandwidth rates returning higher resolution of imagery. The current WGS constellations offer users between 1-3 gigabytes per second (Gbps) of bandwidth (NSCC Study Guide, 2003). There is very little difference between images gained utilizing 1-3 Gpbs, although this difference in the amount of bandwidth available will decrease total processing time, it has little bearing on the quality of imagery. A single TSAT satellite may provide users with 10 Gbps of bandwidth and the full constellation is estimated to provide 40 Gbps of accessible bandwidth for the tactical user (Katzman, 2006). The estimated value for available bandwidth and graph of the value function are shown in Figure 34.

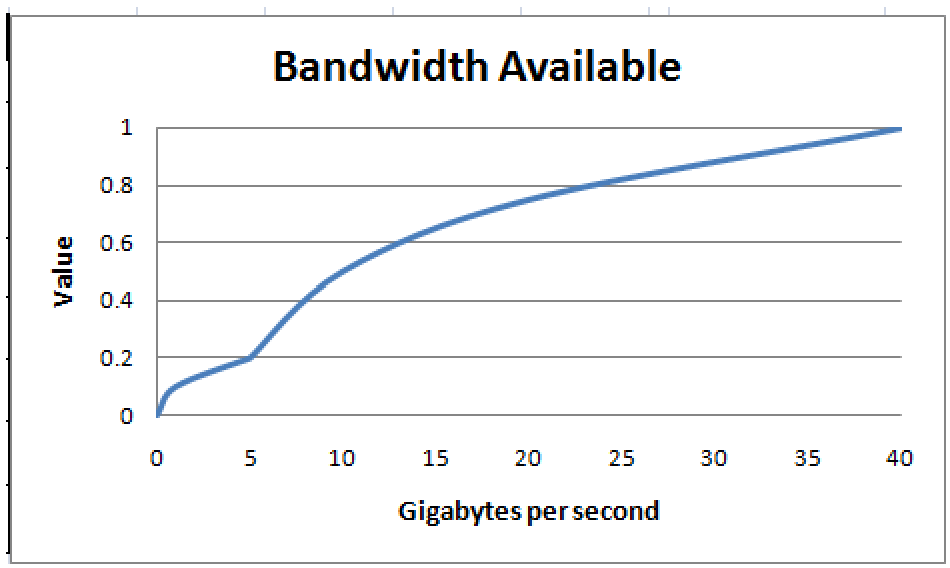


Figure 34. Quality of imagery value measure function

4. Surveillance Coverage

Surveillance coverage is measured by the percentage of roadway in the AO covered in a 24-hour period, with higher percentages resulting in greater value to the commander. Sensor systems with limited fuel, battery capacity, or endurance capability may result in information gaps and decrease the value of the system. While UAS with

higher flight ceilings may be able to cover greater distances, stationary cameras provide constant coverage of selected high-risk areas. The estimated value for surveillance coverage and the resultant return to scale graph of the value function are shown in Figure 35.

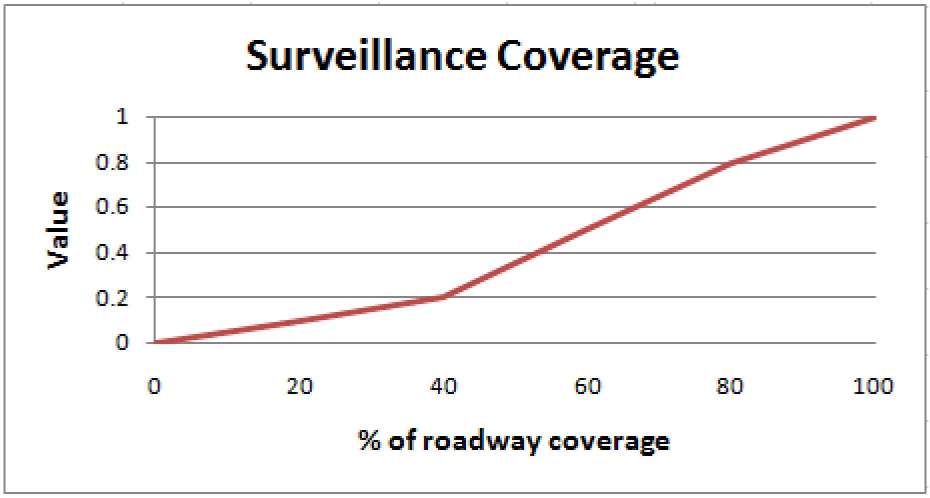


Figure 35. Surveillance coverage value measure function

5. Payload Capacity

A sensor system that has the capacity to carry a heavy payload allows for greater flexibility in swapping out older systems with updated versions that may have higher weight requirements. Payload weight capabilities are increasing, meaning more variety and sizes of payloads can be made available. Physical sensor capabilities change more slowly than payload capabilities so users may choose to upgrade the payload before sensor itself. In many cases, it is the payloads' capabilities that become the mission's bottleneck and therefore crucial for mission success (Frost & Sullivan, 2005). The ability to carry various sensor platforms allows for mix and matching of visual cameras for viewing live footage, electro-optic, and IR sensors for day and night surveillance and thermal imaging, and two types of radar (synthetic aperture radar and motion direction indication) (Frost & Sullivan, 2005). Stand-alone systems with just visual cameras carry a payload of about 2 lbs (Goebel, 2009) and fully loaded systems operating at the Brigade level usually require a payload capacity of 75 lbs (DragonFly Pictures, 2009), therefore

systems operating at the BCT level's value greatly increases at 75 lbs. The estimated value for payload capacity, and the resultant graph of the value function are shown in Figure 36.

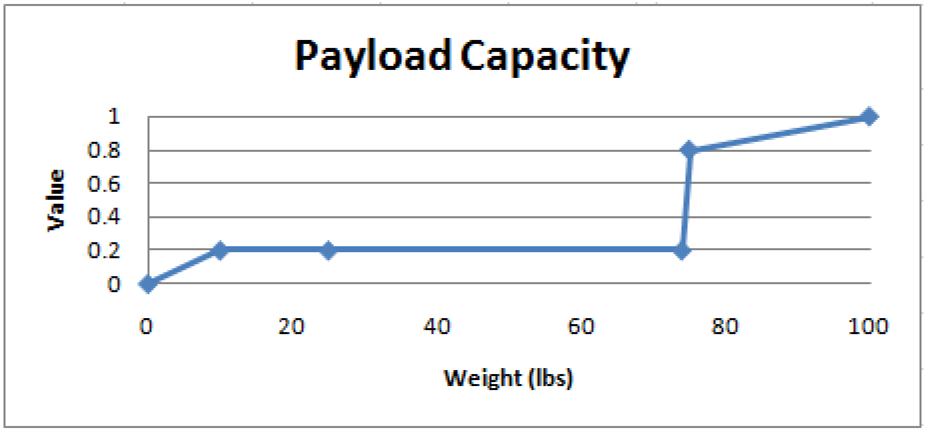


Figure 36. Payload capacity value measure function

6. Meta-Data Tagging

Maximizing the number of sensors operating under a BCT's control that have meta-data tagging capability improves a commander's quality of information. The limits of the x-axis are set for the number of sensors with meta-data tagging capability for what an ideal solution and worst-feasible solution would have for the number of sensors with meta-data tagging capability. Utilizing our operational scenario, we assume the maximum number of unmanned sensors operating in a BCT's AO is five and the minimum is the absence of meta-data tagging for all sensors or zero. If only one sensor has meta-data tagging capability, the system's value is increased very little, since this data may be merged with imagery from higher platforms, but has little utility for the immediate users within the BCT. The value increases at a much higher rate for two or more sensors, since data within the BCT can now be fused to create a more complete and accurate set of information for the commander, and results in an estimated concave return to scale curve, shown in Figure 37.

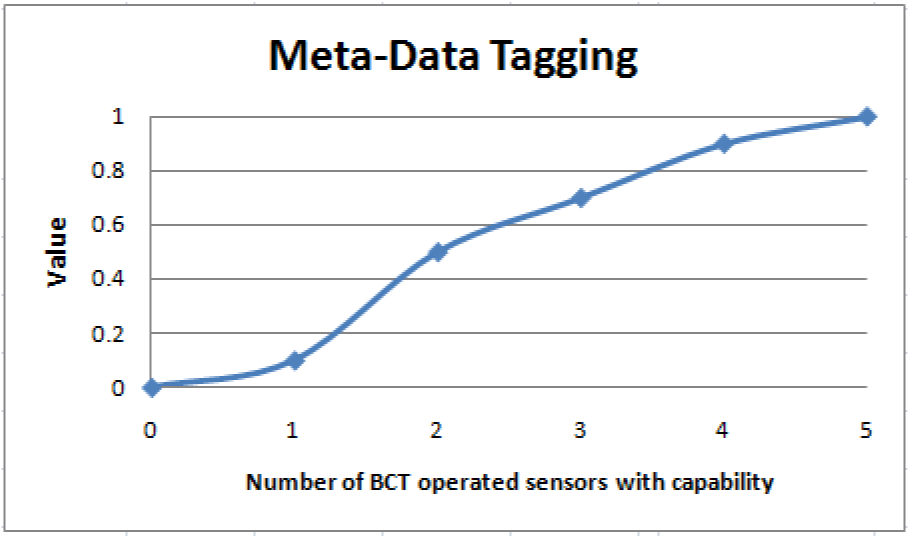


Figure 37. Meta-data tagging value measure function

7. Processing Time

Minimizing the amount of time it takes an unmanned sensor to transmit imagery or video and the time it takes the data to be processed, analyzed, and sent to the commander improves the timeliness of information gain. Current imagery transmit times can take over 12 minutes for streaming video, while updated systems are projected to cut this to under a second (Katzman, 2006). The lack of meta-data tagging and data fusion software for current systems delay analysis, while the combination of these capabilities would dramatically improve the analysis process. The estimated value for payload capacity, and the resultant decreasing return to scale graph of the value function, are shown in Figure 38.

Processing Time	Value
30	0
25	0.1
20	0.5
15	0.7
10	0.9
5	1

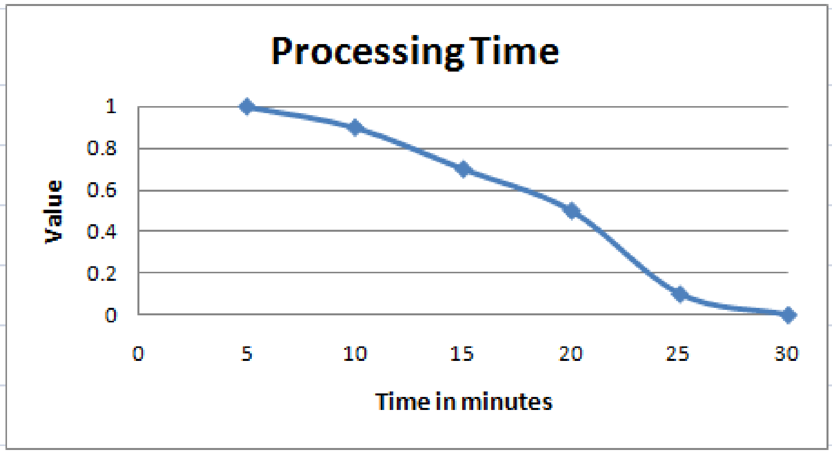


Figure 38. Processing time value measure function

8. Units with Real-time Imagery

The value measure function for real-time imagery was created utilizing the operational scenario and assuming there are five or fewer units capable of receiving real-time imagery within the BCT's area of operations. Situational awareness across the battlefield improves as the number of units with shared real-time imagery increases (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2008). The estimated value for units with real-time imagery, and the resultant linear return to scale graph of the value function, are shown in Figure 39.

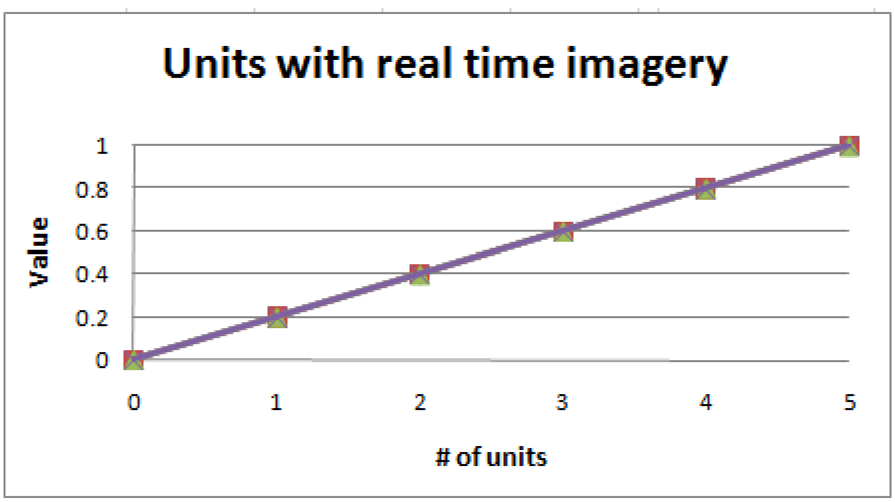


Figure 39. Real-time imagery value measure function

9. Probability of Detection and Identification

Maximizing a sensor's probability of detection and probability of identification improves the accuracy and value of a commander's information gain. The higher the probability of detection and identification, the fewer Soldiers that are put at risk. Similarly, the lower the probability of false detection and false identification improves the accuracy and value of a commander's information gain. Sensor systems that are able to properly detect and identify IEDs allow commanders to quickly take action to neutralize the threat and decrease the threat to coalition forces and the local populace. High probabilities of detection and identification as well as low false detection and false identification rates were greatly valued by survey respondents. The estimated value for the probability of detection, probability of false detection, probability of identification, probability of false identification, and the resultant return to scale graphs of the value functions are shown in Figure 40.

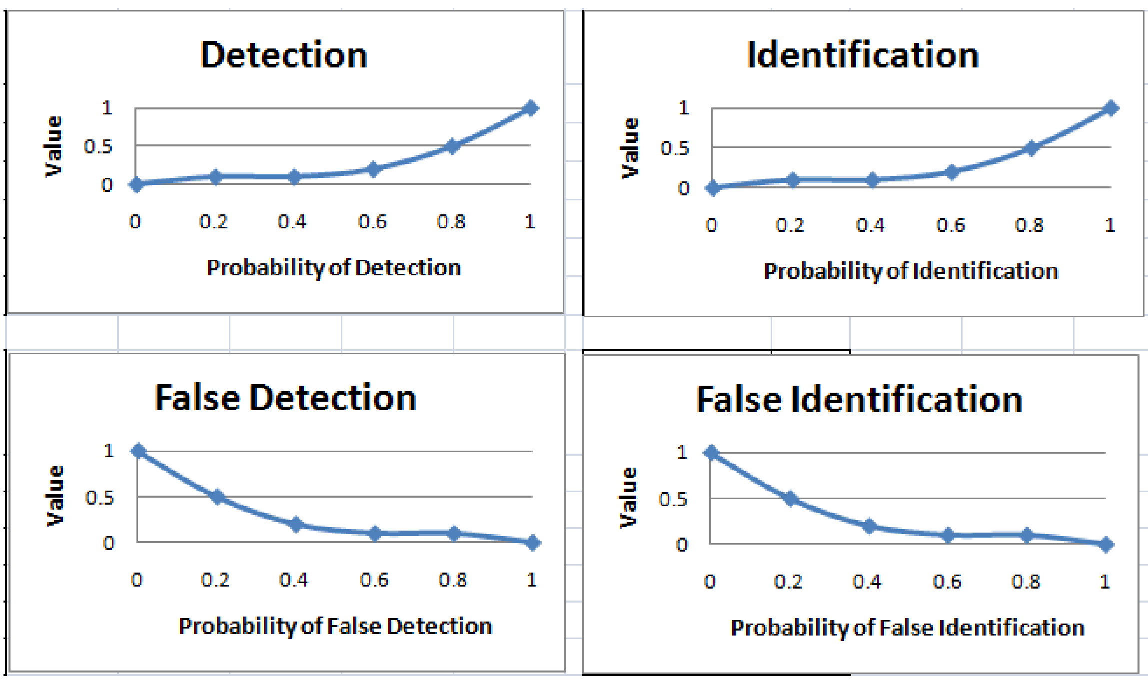


Figure 40. Detection and identification value measure functions

10. Reliability

The reliability of an unmanned sensor system is dependent on the reliability of each sensor operating within the system. Calculating reliability of the system using a series RBD means that each sensor must be operating as intended for the system to function properly—the higher the overall system reliability, the greater the system's value to the commander. The estimated value for reliability, and the resultant return to scale graph of the value function, are shown in Figure 41.

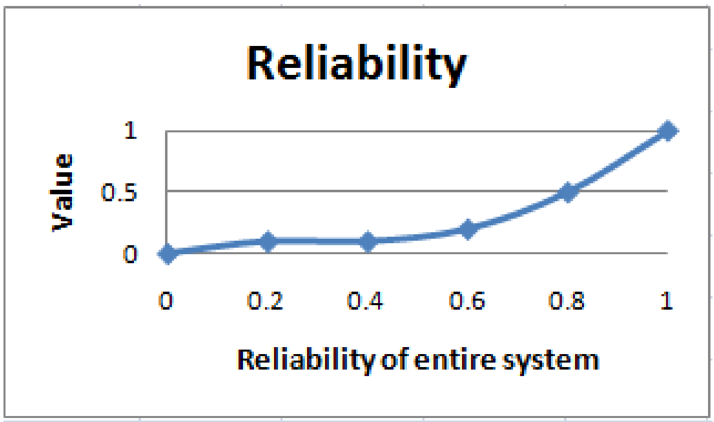


Figure 41. Reliability value measure functions

11. Maintainability

Maintainability is the ability of an item to be retained in or restored to a specific condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources at each prescribed level of maintenance and repair. The percentage of maintenance personnel trained to repair unmanned sensor system equipment within a BCT greatly improves the systems' life span and contributes to greater system maintainability. The percentage of repair parts available in the unit-level logistics system decreases a system's down time. The estimated value for percentage of maintenance personnel trained to repair unmanned sensor systems, the percentage of repair parts available in the unit-level logistics system, and the resultant return to scale graph of the value functions are shown in Figure 42.

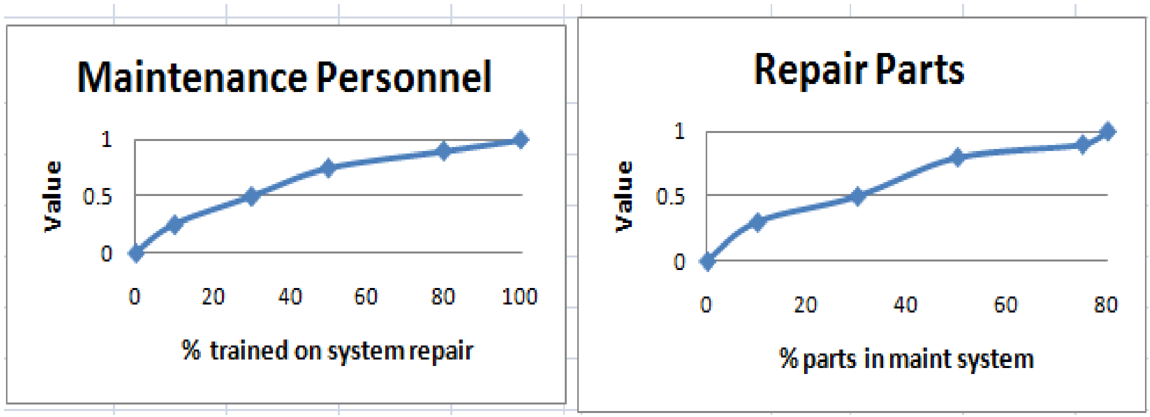


Figure 42. Maintenance value measure functions

12. Soldier Survivability

It terms of providing SA in the C-IED fight utilizing unmanned sensors, the key component of maximizing Soldier survivability is reducing physical and mental fatigue on the Soldier. Reducing physical and mental fatigue is measured by the physical, cognitive, and workload constraints placed on the Soldier by the system (Payan & Zigler, 2008). Reducing the total training time and physical workload for Soldiers frees up time for performance of primary duties, rest, or gaining proficiency in operational tasks. Measuring the actual training time or physical workload required by an individual Soldier for each sensor system is difficult to estimate. The values for these functions were estimated comparing the potential systems impact on a unit in comparison to the current system. A constructive scale, with the following values, was used to compare the alternative to the current system:

- –1 worse than current system.
- 0 same as current system.
- +1 marginal improvement to current system.
- +2 some improvement to current system.
- +3 significant improvement to current system.

The estimated value for individual Soldier training time for a complete system, the value for the physical workload, and the resultant return to scale graph of the value functions are shown in Figure 43.

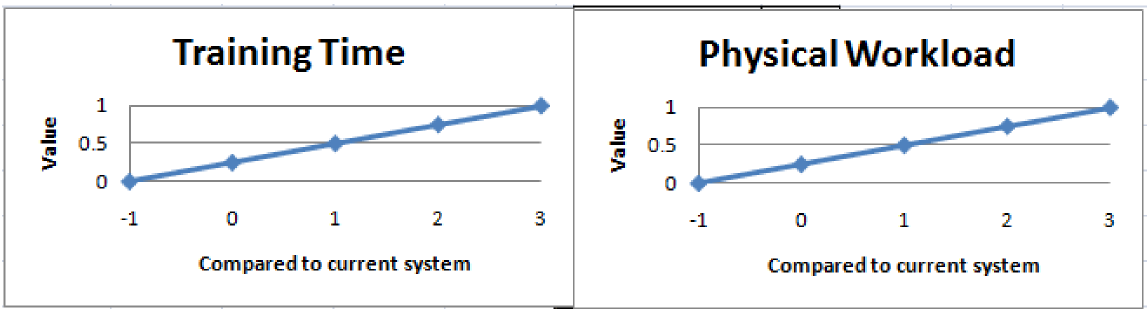


Figure 43. Survivability value measure functions

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IV. SOLUTION DESIGN

A. OVERVIEW

The second phase of the systems engineering process is solution design and consists of generation of alternatives and solution analysis. Alternatives will provide the decision makers with a variety of possible solution sets to a single problem. Each alternative has its own inherent risks and uncertainties, which are identified and described so that the decision maker has a clear picture of possible trade-offs, shortcomings, and appropriate mitigation techniques.

To ensure that all the significant system functions, as described in the functional hierarchy and reviewed in the objectives hierarchy, are adequately addressed in the generation of alternatives, the system design elements are broken down into partitions or sectors. These partitions reflect those major system functions, and through the use of a morphological box each of the sectors, are allocated to possible hardware systems or technologies under development. This technique is often called functional allocation (Blanchard & Fabrycky, 2006). Brainstorming is an essential step in functional allocation, as it is utilized to place solution possibilities in the morphological box, shown in Table 6. A morphological box divides a problem into segments and identifies several solutions for each segment (Buede, 2000). The three functions (observation, information processing, understanding the environment) are listed above the potential solutions, which represent specific instantiations of ways to achieve the desired function. For example, while each item listed in the observe sector has the capability to perform some type of observation, its placement as an option does not mean that using only that item maximizes the observe function. Pairing of various systems within each category, or from multiple categories, may result in better observation techniques than utilizing just a single asset. Essentially, this morphological box covers the potential human components, technology, and unmanned sensor systems and which functions they accomplish.

Observation Options			
UASs	**Cameras**	**UGVs**	**HUMINT**
Raven Shadow Wasp Tern Condor Dark Star Gnat Hunter Pioneer Global Hawk	JLENS/RAID JLENS/BLIMP JLENS/ORBIT G-BOSS	TALON ARV-RSTA MULE RONS MDARS-E PACKbot	Soldier Civil Affairs Psychological Operations Local Populace Informants Detainees Enemy
Information Processing			
Technology		**Satellites**	**Human Component**
Meta-Data Tagging Payload Data Fusion Software JAUS Compliance Bandwidth Frequencies Resolution of Displays Resolution of Imagery/Video		WGS DSCS Milstar TSAT AEHF	Commander Intelligence Officers Data Analysts Soldier UAS/UGV Operators
Understanding Environment			
Technology		**Information**	**Human Component**
Data overlays Shared Imagery		Accurate Complete Timely	Commander Intelligence Officers Data Analysts Soldier Coalition Forces Local Populace Informants Detainees Enemy

Table 6. Morphological Box of functions and options

B. GENERATION OF ALTERNATIVES

The generation of alternatives is based on the conduct of design synthesis. Synthesis is the "creative process of putting known things together into new and more useful combinations. Meeting a need in compliance with customer requirements is the objective of design synthesis" (Blanchard & Fabrycky, 2006, p. 40). Therefore, the proposed alternatives are comprised of a proposed mix of unmanned sensor systems as

described in Chapter II, address the objectives identified and described in Chapter III, and are intended to be utilized for the operational scenario as described in Chapter III.

The baseline system is based on input gathered from officers deployed as a part of the 2nd Brigade Combat Team of the 101st Airborne Division (Air Assault) during the summer and fall of 2008, and the capabilities their BCT emplaced in an operational scenario similar to the one utilized in this research. The "near-term" alternative combines unmanned sensor systems that would be available for fielding by 2015 with current sensor systems. The near-term solution includes systems that have completed research development tests and are being prepared for fielding. The "long-term" alternative combines satellite systems, and unmanned sensor systems that may be available in the next 10-15 years. All of the systems in the long-term alternative are being considered by the military for implementation or continued funding. Each of the proposed alternatives is described in detail below, to include: system specifications; discussion and graphic of "battlefield flow," or how the synthesized alternative is employed; DOTMLPF considerations, particularly nonmaterial aspects of implementing this alternative; and a brief summary of drawbacks associated with this alternative. Table 7 shows the proposed sensor systems for each alternative.

	Alternatives		
Objectives	**Alt 1: Baseline**	**Alt 2: Near-Term**	**Alt 3: Long-Term**
Observe	Raven JLENS/RAID	Wasp JLENS/RAID	Wasp JLENS/ORBIT
Process	WGS DSCS Milstar	WGS DSCS Milstar	TSAT AEHF
Understand Environment	Raven JLENS/RAID MARCbot	Wasp JLENS/RAID MULE	Wasp JLENS/ORBIT MULE

Table 7. Alternatives

1. Alternative 1: Baseline

a. Specifications

A baseline system, shown in Figure 44, was established consisting of those sensor systems currently utilized by BCTs deployed to Iraq or Afghanistan for the operational scenario described in Chapter III. Current SHF MILSATCOM systems consist of the DSCS, WGS, and Milstar. These satellites are capable of narrow beam coverage to stationary command posts (CPs), providing real-time streaming video and imagery. The Raven is managed at the battalion level and is often pushed down to maneuver companies. The Raven is launched by hand and can fly at an altitude of 1,000 feet, at speeds up to 52 knots. The MARCbot is pushed down to the maneuver company level and divided up among platoons. MARCbots are small, remote-controlled robots that use an attached camera to seek out, identify, and confirm possible IEDs. The majority of the camera systems being used in theater are JLENS and are combined with the RAID tower. The JLENS camera sensor is networked to a Base Defense Operations Cell, which projects the video feed with digitized map overlays (Burlas, 2004).

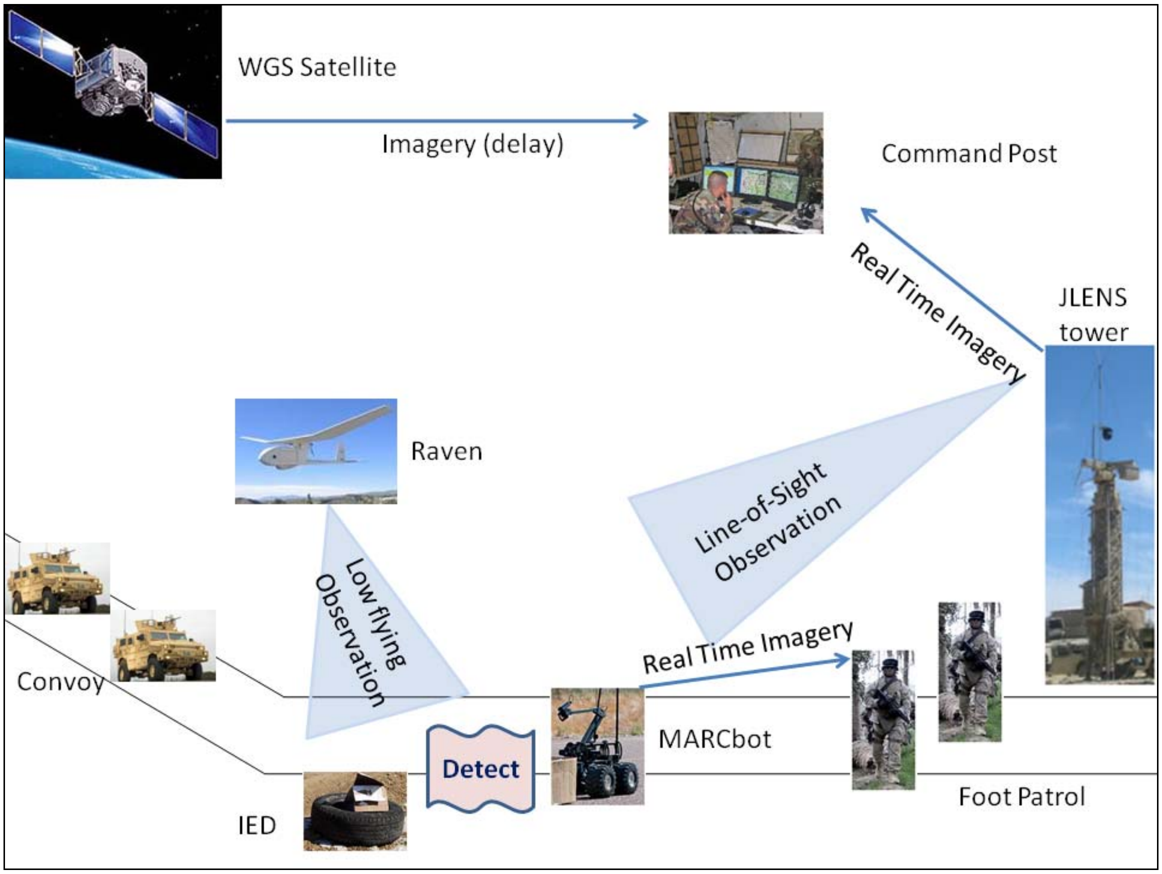

Figure 44. Alternative 1: Baseline

b. *Battlefield Flow*

The utilization of unmanned sensors in providing SA in the C-IED fight begins with the *observe phase*. The JLENS/RAID tower provides passive sector search capability for line of sight, while the Raven provides a mobile platform that is capable of responding to immediate user desires and beyond-line-of-sight search radius.

Information processing is achieved throughout the transmission as each unmanned sensor system sends data to the user. The JLENS/RAID tower is hard-wired into the CP and imagery is received instantaneously. The JLENS/RAID does not require satellite access and its imagery can immediately be analyzed and viewed by the user. The Raven and MARCbot rely on data transfer via satellite for imagery to reach the intended user. The Raven's data is sent directly to the CP from the satellite, with 5–10 minute delays from sending to receiving transmission. Convoys and Soldiers on the ground are

not able to receive imagery from the Raven due to satellite limitations. The MARCbot's data is sent directly to the Soldier controlling it, is not tied into the Raven's imagery, is not accessible to the CP, and is not received by data analysts.

Understanding the environment in our operational scenario once an IED is suspected requires the utilization of active search measures. A MARCbot is employed by Soldiers on the ground to inspect the suspicious item. The MARCbot is controlled remotely by the Soldier and has an observation range of greater than 300 ft. The remote control unit has a 12-ft antenna, which allows the Soldier controlling the robot to remain in an armored vehicle during operation. While the actual control range is classified, it exceeds military recommendations for line-of-sight standoff distance (IEDrobot.com, 2006). Only the Soldier controlling the MARCbot is able to view the video feed and further voice or data relay between the Soldier and the CP is required for commanders to gain information on the suspected IED.

c. DOTMLPF Implications

Training and Personnel

Units are currently receiving predeployment training, including maintenance and recovery operations, on all systems included in the baseline system. This alternative does not require any additional personnel allocations for a BCT.

d. Drawbacks

Current satellite systems lack the bandwidth capabilities to provide users with communications on the move, or unified imagery across the battlefield. The CP is the only element in this scenario that is receiving real-time imagery from Raven via the satellite and from a direct feed from the JLENS/RAID tower. The MARCbot's imagery is received only by the Soldier controlling it, and is not accessible to vehicle convoys or the CP. The MARCbot was not designed to physically touch, bump, modify, or attempt to disable suspected IEDs and does not have user repair parts (IEDrobot.com, 2006).

2. Alternative 2: Near-Term

a. Specifications

The near-term solution includes systems that have completed research development tests and are being prepared for fielding. For Alternative 2, shown in Figure 45, the Raven was replaced with the Wasp. The Wasp has successfully completed development and test milestones. The system is a modular design that allows the aircraft to be separated into components and is man-transportable. It takes two operators to launch and can fit into a HMMWV system. While the Raven must be launched relatively close to the desired search area because of its shorter endurance, the Wasp can be launched farther away, decreasing the overall risk to personnel. The Wasp has a faster flight speed, 110 knots compared to the Raven’s 52 knots, a higher flight ceiling, 15,000 ft compared to 1,000 ft, as well as greater flight endurance, 4.5 hrs compared to 1.5 hrs. The Wasp’s data is able to be fused with other FCS systems using current software packages.

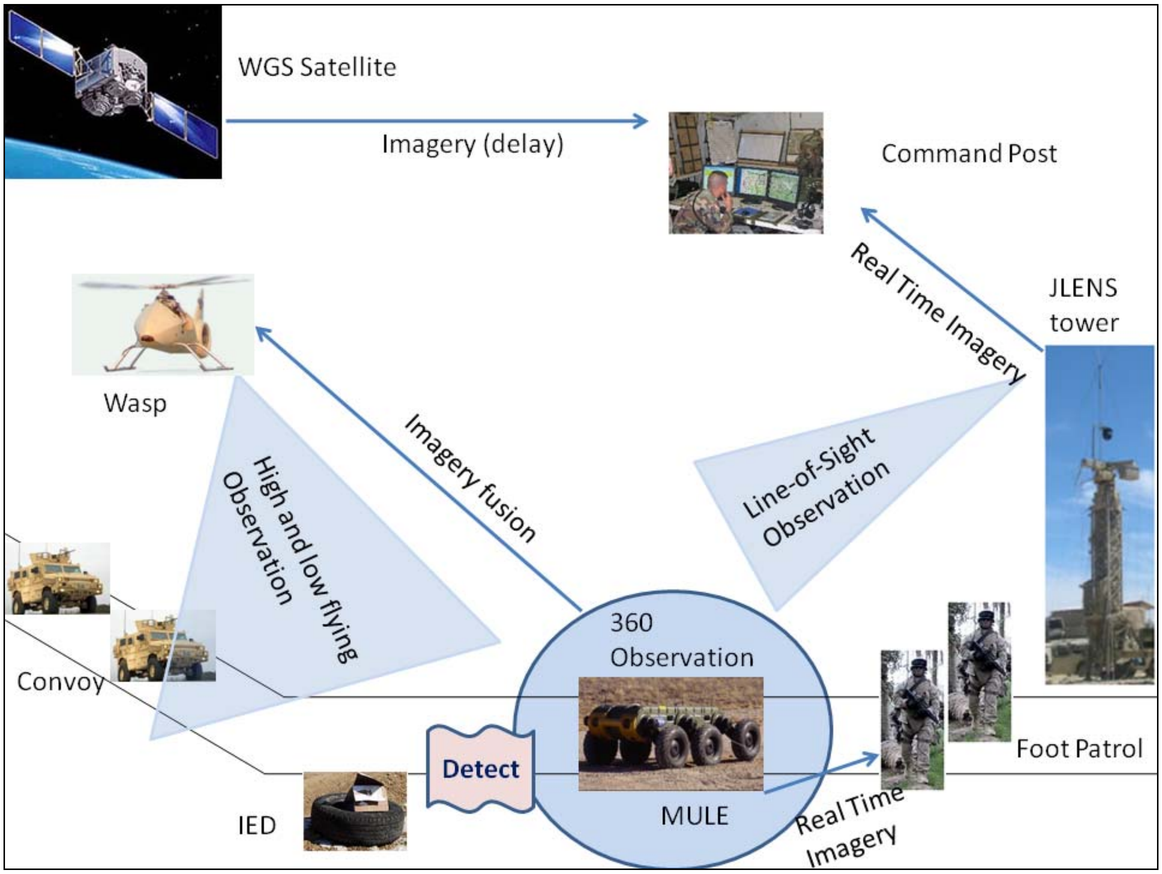

Figure 45. Alternative 2: Near-Term

The second unmanned sensor change is the utilization of the MULE instead of the MARCbot. The MULE is an unmanned platform that provides transport of equipment and supplies in support of dismounted maneuver and has day and night thermal, infrared, and forward-looking imaging systems, which are all JAUS compliant. The MULE can also communicate with UASs to provide additional sensor information in the development of a COP. The MULE is projected to be part of the FCS and is designed to be maintained with only 10 tools. The MULE can locate buried IEDs with ground-penetrating radar and can neutralize the threat (Govers, 2008).

b. Battlefield Flow

The utilization of unmanned sensors in providing SA in the C-IED fight begins with the *observe phase*. The JLENS/RAID tower provides passive sector search

capability for line of sight, while the Wasp provides a mobile platform that is capable of responding to immediate user desires and beyond-line-of-sight search radius. The Wasp's high flight speed and ability to search at high elevations provides faster sector searches with greater distances and has little impact on the local populace. The Wasp's sensor package provides greater resolution than the Raven during both day and night operations. The MULE moves with dismounted patrols and provides additional camera angles for 360-degree observation as well as ground-penetrating radar to search for buried IEDs.

Information processing is achieved throughout the transmission as each unmanned sensor system sends its data to the user. The JLENS/RAID tower is hard-wired into the CP and imagery is received instantaneously. The Wasp and MULE rely on data transfer via satellite for imagery to reach the intended user. The Wasp's data is sent directly to the CP from the satellite, with 5–10 minute delays from sending to receiving the transmission. Convoys and Soldiers on the ground are not able to receive imagery from the Wasp due to satellite constrictions. The MULE's data is sent directly to the Soldier controlling it and its imagery can be sent to a UAS, in this case the Wasp, for data fusion and transmission to the CP.

Understanding the environment in our operational scenario once an IED is suspected requires the utilization of active search measures. The MULE's radar assists in the identification and classification of a suspicious item, as well as its neutralization. The commander has access to all imagery and data images with a transmission delay due to satellite bandwidth restrictions. The WGS satellite constellation does not provide for communications on the move, so convoys and foot patrols will not have real-time access to the same imagery as the CP.

c. DOTMLPF Implications

Training

The Wasp and MULE will require additional predeployment training for operators. The MULE is designed to move with a dismounted patrol, and carries ground-penetrating radar capable of neutralizing IEDs. The MULE will need to be

incorporated into unit's movement drills and should be utilized at military training centers prior to a unit's deployment. In-theater training is not currently available, and a direct fill is not advised for the MULE due to its size and weapons platform (Govers, 2008). Maintenance personnel could be trained on unit-level maintenance in theater, but a week-long training program is recommended (Govers, 2008).

A home-station training program is in development for the implementation of the Wasp (Office of the Secretary of Defense, 2007). The Wasp's maintenance training is projected to be included in its initial home-station fielding (Office of the Secretary of Defense, 2005).

Personnel

The Wasp requires a two-person launch team, but the procedure is relatively simple and can be launched by Soldiers of any military occupational specialty (Dragonfly Pictures, 2009). The Wasp's maintenance will not require additional maintenance personnel for unit-level maintenance; however, civilian technicians are projected to be required for depot level maintenance and certain payload issues (Office of the Secretary of Defense, 2007). The MULE is designed to be maintained with only 10 tools and will not require personnel changes for a BCT. Civilian technicians may be required for depot-level maintenance and payload issues (Office of the Secretary of Defense, 2007).

d. Drawbacks

While the Raven is often pushed down to maneuver companies, the Wasp will be held at the brigade level and employed for higher mission sets, which limits the total number of Wasps employed within a BCT. The Wasp weighs significantly more than the Raven, 475 lbs to 4l lbs, and must be transported by vehicle as opposed to being man-portable. The MULE is a full-sized, 2.5-ton unmanned vehicle and, while it is designed to go where the Soldier goes, it is not as portable as the MARCbot.

3. Alternative 3: Long-Term

a. Specifications

Alternative 3, as shown in Figure 46, was designed as a possible long-term solution set. The "long-term" alternative combines satellite systems and unmanned sensor systems that may be available in the next 10–15 years. All of the systems in the long-term alternative are being considered by the military for implementation or continued funding. The use of the AEHF and TSAT would greatly decrease time to receive imagery, since it allows the high-data rate access and provides a data rate of 2.5 gigabits to 10 gigabits per second through laser communications. The quality of imagery and video resolution are a function of the frequencies used by the sensor and the bandwidth allocated from the satellite. Compared to Milstar, the AEHF system program improvements include higher data rates (8.192 Mbps), which allows for a sharper image and more bandwidth than the current system.

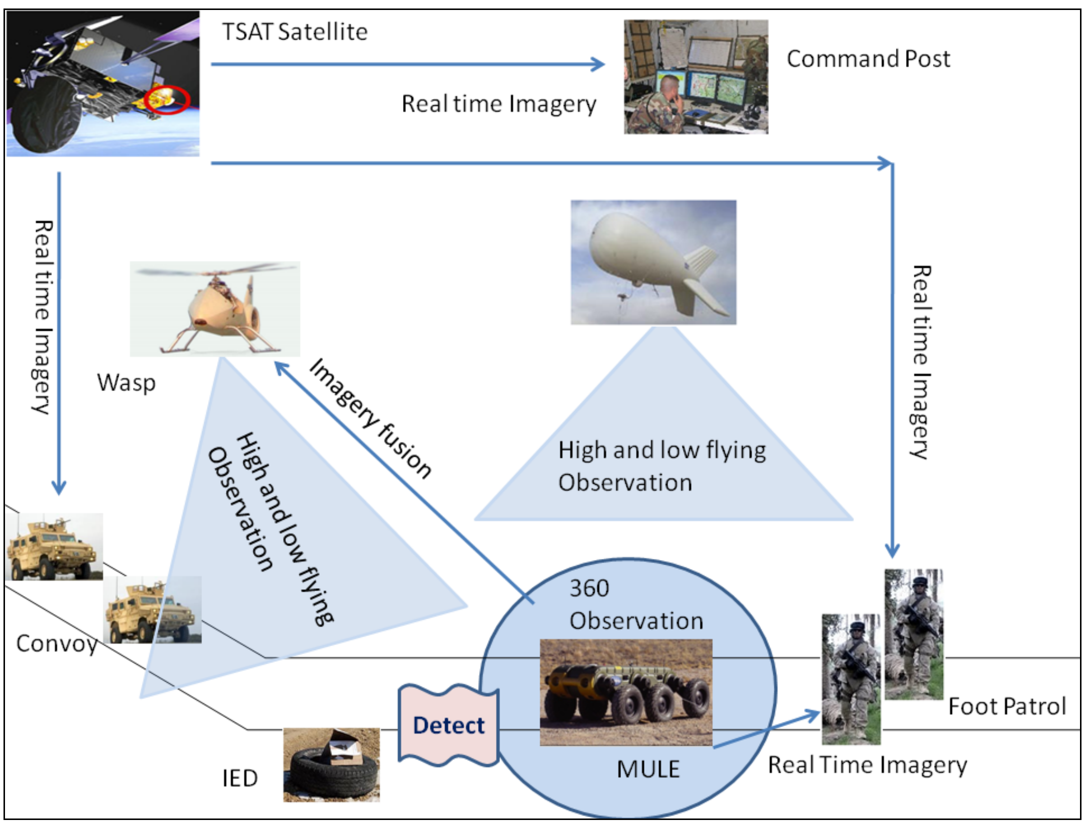

Figure 46. Alternative 3: Long-Term

The JLENS/ORBIT consists of two systems: a surveillance system and a fire-control system, which includes elevated, long-range surveillance radar and elevated, high-performance fire control radar. Each radar is integrated onto a large aerostat connected by a tether to the ground-based mobile mooring station and communications processing group. The JLENS/ORBIT provides for long-duration, wide-area, over-the-horizon observation. Its advanced communication capabilities allow for faster data transmission and its advanced sensor package provides greater spatial resolution than the JLENS/RAID.

b. Battlefield Flow

The utilization of unmanned sensors in providing SA in the C-IED fight begins with the *observe phase*. The JLENS/ORBIT system provides for passive wide-area, over-the-horizon sector search. The Wasp provides a mobile platform that is capable of responding to immediate user desires with quick reaction time. The JLENS/ORBIT and Wasp's ability to search at high elevations provides larger search parameters. The JLENS/ORBITs advanced sensor package provides greater resolution than the JLENS/RAID during both day and night operations. The MULE moves with dismounted patrols and provides additional camera angles for 360-degree observation, as well as ground-penetrating radar to search for buried IEDs.

Information processing is achieved throughout the transmission as each unmanned sensor system sends its data to the user. The use of TSAT and AEHF, instead of DSCS, WGS, and Milstar, will have a tremendous impact on battle management. Imagery from a UAV that would typically take 2 minutes to process using the Milstar II system, or radar imagery from a Global Hawk, which traditionally takes about 12 minutes to process, would both take less than a second using TSAT (Katzman, 2006).

Understanding the environment in our operational scenario becomes important once an IED is suspected, and requires the utilization of active search measures. The MULE's radar assists in the identification and classification of a suspicious item, as well as its neutralization. Users will receive real-time streaming video and imagery. TSAT is the only satellite constellation that is capable of providing

communications on the move, therefore ensuring unified imagery across the battlefield. The CP will be looking at the same video feed that Soldiers on the ground, or convoy commanders are viewing.

c. DOTMLPF Implications

The utilization of TSAT and AEHF will greatly impact the SA of Soldiers on the battlefield. Communications on the move and real-time imagery accessible across the battlefield will impact military doctrine, training, leadership, and personnel. Commanders will no longer be the only ones with real-time imagery and decisions will be made at lower and lower levels. Doctrine will need to be re-looked and new TTPs developed to ensure the safety and efficiency of Soldiers. TSAT and AEHF may actually increase personnel requirements, since the amount of available information will increase exponentially and the current allocation of analysts will be overwhelmed (Katzman, 2006).

d. Drawbacks

The Pentagon's recent postponement of the TSAT contract award until FY2010 means the satellite package will not be available until FY2019, thus greatly limiting the Army's planned use of the FCS and future bandwidth accessibility (Shala-Esa, 2008). The cost of both the TSAT and the JLENS/ORBIT systems is significant.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This research develops a systems engineering framework to examine how unmanned sensor technologies can be used to improve SA against IEDs. The current satellite, UAS, UGVs, and camera systems used in theater were described, along with their basic physical and performance capabilities. Future systems were also described for consideration in the generation of alternatives.

A systems engineering design process is used to provide a framework with which to analyze this problem. The problem definition phase resulted in the top level objectives of *providing SA*, *maximizing operational suitability,* and *maximizing Soldier survivability* are the top-level objectives in the effective employment of unmanned sensors in C-IED. Quantitative measures, defined as MOPs, are proposed for each of these qualitative functions.

Providing SA consisted of maximizing the ability to *observe the battlefield*, *process the information*, and *understand the environment*. Achieving SA in the C-IED fight includes the ability to observe the battlefield using HUMINT and SIGINT. SIGINT must be processed into quality and valuable information prior to being of use to a commander. Achieving SA in the C-IED fight also includes the ability to monitor and recognize convoys, friendly, neutral and enemy forces, as well as environmental factors. Commanders need to be able to determine pattern recognition, and see disturbed soil patches. Ideally, multiple Soldiers on the ground, commanders in TOCs, and data analysts would have access to the same imagery and be able to determine the attributes and dynamics of hostile events and forces.

Operational suitability is the degree to which a system can be satisfactorily placed in field use with respect to RAM, supportability, HSI, and interoperability. This research focuses on the impact of reliability and maintainability in the emplacement of unmanned sensor systems in the C-IED fight. These two components were selected because they are important considerations from both the system and individual Soldier perspective.

Equipment utilized in combat must be able to perform at a high performance level for a sustained period of time. When new or updated systems are introduced without sufficient operational testing or with an expedited time line, military maintenance capabilities are limited. The MOPs for operational suitability are system reliability, percentage of unit maintenance personnel trained to repair equipment, and percentage of repair parts available in unit level logistics system.

In general, Soldier survivability consists of six key components: reduce fratricide, reduce detectability of the Soldier, reduce probability of being attacked, minimize damage, minimize injury, and reduce physical and mental fatigue (Payan & Zigler, 2008). It terms of providing SA in the C-IED fight utilizing unmanned sensors, the key component of maximizing Soldier survivability is reducing physical and mental fatigue on the Soldier. Reducing physical and mental fatigue is measured by the physical, cognitive, and workload constraints placed on the Soldier by the system (Payan & Zigler, 2008). The MOPs for Soldier survivability are training time and physical workload.

The second phase of the systems engineering process is solution design and consists of generation of alternatives and solution analysis. To ensure that all the significant system functions, as described in the functional hierarchy and reviewed in the objectives hierarchy, are adequately addressed in the generation of alternatives, the system design elements are broken down into partitions or sectors. Three alternatives were generated: baseline, near-term, and long-term. The base-line system consists of current unmanned sensors, and satellites used by the Army; the near term system includes systems that have completed research development tests and are being prepared for fielding, and the long term system combines satellite systems and unmanned sensor systems that may be available in the next 10–15 years. Each alternative’s basic specifications, battlefield flow (highlighting each unmanned sensor’s use for observe, detect, and battle management), and drawbacks are addressed.

B. RECOMMENDATIONS AND AREAS FOR FUTURE RESEARCH

The analysis conducted in this research is only a starting point for improvements in meeting the war-fighters' desires in providing SA in the C-IED fight. Although the methodology used in this thesis provides a framework for pairing war-fighter desires with current and future unmanned sensor systems, further alternatives may be generated for use in decision making and solution implementation. Recommendations for future research in the area of improving SA in the C-IED fight through unmanned sensors include:

- Performance analysis could be conducted to evaluate the performance and effectiveness of system alternatives in providing SA in the C-IED, based on the needs analysis, objectives hierarchy, and associated evaluation metrics developed in this thesis. The three alternatives could be evaluated and analyzed with reference to various operational scenarios.
- The life-cycle cost of each proposed alternative used to perform the identified system functions of observe, detect, and battle management could be researched and estimated. This would allow for a cost-benefit analysis of the different alternatives and allow the decision maker to understand the relationship between increased cost and predicted performance.
- The conduct of a thorough risk analysis of each alternative, particularly in the areas of technological risk, would be very useful. Risk analysis, and subsequent risk management, is a cyclic process that is executed continuously throughout a program's life cycle and is an important part of systems analysis. It is especially beneficial at the early stage of the system life cycle.
- Modeling and simulation-based analysis of alternatives. Each alternative could be modeled and simulations run to see how the proposed combination of sensors impacts a commander's ability to perform each function of providing SA.

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APPENDIX A. STUDENT SURVEY

Naval Postgraduate School
Institutional Review Board (IRB)

9 Jan 09

From: LCDR Paul O'Conner
To: Associate Professor Eugene Paulo
MAJ Shannon Whiteman

Subject: YOUR PROJECT: SURVEY ON SITUATIONAL AWARENESS IN THE COUNTER-IED FIGHT

1. The NPS IRB is pleased to inform you that the NPS Institutional Review Board has approved your project (NPS IRB# NPS20090035-IR-EP7-A).
2. The NPS IRB was originally certified by BUMED on 26 July 2002 and has been re-certified until 30 August 2009.
3. This approval expires on June 30, 2009. Please submit a copy of all records and consent forms to the Research and Sponsored Programs Office (Laura Ann Ikner-Price, Halligan Hall, Room 201B) at the conclusion of this project.
4. If your protocol changes at any time, you will need to resubmit your project proposal to the NPS IRB.

Under 32 CFR 219.116(d), the IRB finds that the requirement to describe procedures may be altered so that subjects receive the attached debriefing information after their participation.

Sincerely,

Paul O'C

LCDR Paul O'Conner
Chair
NPS Institutional Review Board

Situational Awareness in Counter-IED fight

Informed Consent

INTRODUCTION: You are invited to participate in a research study entitled "Situational Awareness in the Counter-IED Fight".

PURPOSE:
The purpose of this survey is to explore what aspects of situational awareness in the counter IED fight are most important to active duty Army officers who have deployed in support of OIF or OEF. Your deployment experiences with IEDs are invaluable and of great interest to the Joint IED Defeat Organization. The results of this survey will b used to propose various sensors or system combinations that best meet what you, the warfighter, believes is most important during combat. Time to complete the survey should be less than 30 minutes.

RISKS:
Your responses will be linked to your email address which will only be available to the researcher. Please note that survey records and data will be kept strictly confidential. Your participation in the survey and your responses to th survey will not be disclosed outside of the research team. However, survey results will only be reported in the aggregate so that individual responses cannot be determined

BENEFITS:
The results of this survey will be provided to the Naval Postgraduate School as part of an Active Duty Army Studer Thesis on the subject above. Results of that Student Thesis will be provided to the Joint IED Defeat Organization t assist in potential changes to future or existing counter-IED systems. The Naval Postgraduate School will maintain the raw data files.

COMPENSATION: No tangible compensation will be given. A copy of the research results will be available at the conclusion of the Thesis research by contacting the Systems Engineering Department at the Naval Postgraduate School

CONFIDENTIALITY AND PRIVACY ACT
Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed.
However, it is possible that the researcher may be required to divulge information obtained in the course of this research to the subject's chain of command or other legal body.

VOLUNTARY NATURE OF THE STUDY:
Your participation in this survey is strictly voluntary and if you agree to participate, you are free to withdraw at ar time without prejudice.

POINTS OF CONTACT:
It is understood that should any questions of comments arise regarding this survey, the Principal Investigator, Dr Gene Paulo, 831-656-3452, should be contacted. Any other questions or concerns may be addressed to teh Navy Postgraduate School IRB Chari, LCDR Paul O'Connor, 831-656-3864, peoconno@nps.edu

STATEMENT OF CONSENT
I have read the information provided above. I understand that by agreeing to participate in ths survey, I do not waive any of my legal rights. Please click "Next" if you agree to take this survey.

Situational Awareness in Counter-IED fight

1. How many times have you deployed (for at least 6 months) to either Iraq or Afghanistan since 2003?

- 0
- 1
- 2
- 3 or more

2. Level at which you worked during your most recent deployment:

If you worked at more than one level during this deployment, choose the level at which you had the most command authority:

- Division (Light, Airborne or Air Assault)
- Division (Heavy/Stryker)
- Brigade (Light, Airborne or Air Assault)
- Brigade (Heavy/Stryker)
- Infantry or RSTA Battalion (in a Light, Airborne or Air Assault BCT)
- Brigade Support Battalion (in a Light, Airborne or Air Assault BCT)
- Infantry or RSTA Battalion (in a Heavy/Stryker BCT)
- Brigade Support Battalion (in a Heavy/Stryker BCT)
- Company or below (in a Light, Airborne or Air Assault BCT)
- Company in a BSB (in a Light, Airborne or Air Assault BCT)
- Company or below (in a Heavy/Stryker BCT)
- Company in a BSB ((in a Heavy/Stryker BCT)
- Other type of unit (ie Aviation BDE, Signal Co, EOD, etc)

3. Position that you held during your most recent deployment at the level checked above, if you held more than one position- select the one that you had the most command authority:

- Commander
- XO
- S2
- S3
- Other (please specify)

8. The Army defines situational awareness as:

Knowledge and understanding of the current situation which promotes timely, relevant and accurate assessment of friendly, competitive and other operations within the battlespace in order to facilitate decision making. An informational perspective and skill that fosters an ability to determine quickly the context and relevance of events that are unfolding.

Do you agree with this definition?

- Strongly Agree
- Agree
- Neither Agree nor Disagree
- Disagree
- Strongly Disagree

What may be a better definition? or what is missing in the above definition?

11. In the next few questions we will be discussing DETECTION in the counter IED fight. Detection is broken down into identification and classification.

Which objectives are most important to improving situational awareness through IDENTIFICATION techniques in combat? For the purpose of this survey, identification is the determination of whether an item is a possible IED or if individuals on the ground are possibly enemy forces.

	Extremely Important (5)	Very Important (4)	Moderately Important (3)	Little Importance (2)	No Importance (1)
(A) Time to receive imagery from Unmanned Aerial Systems or Ground Based Cameras					
(B) Quality of imagery (resolution and seamless streaming)					
(C) Improve the probability of identification					

What other objectives do you feel are important in identifing IEDs or enemy forces during combat?

12. In your opinion, which objectives are most important to improving situational awareness through CLASSIFICATION TECHNIQUES for either IEDs or enemy forces in a designated sector? For the purpose of this survey, classification is the positive determination of an IED or enemy forces.

	Extremely Important (5)	Very Important (4)	Moderately Important (3)	Little Importance (2)	No Importance (1)
(A)Time to receive imagery from Unmanned Aerial Systems or Ground Based Cameras					
(B) Time it takes to classify the item					
(C) Reduce risk to military personnel					
(D) Reduce risk to civilians					
(E) Reduce risk to key equipment and infrastructure					
(F) False alarm rates					

What other objectives do you feel are important in classifing IEDs or enemy forces during combat?

Taking Action

13. Which objectives are most important to improving situational awareness through neutralization or deterrence techniques in combat?

	Extremely Important (5)	Very Important (4)	Moderately Important (3)	Little Importance (2)	No Importance (1)
Reduce the risk to military personnel.					
Reduce the risk to host nation civilians					
Reduce the risk to key assets and infrastructure					
Reduce the time to neutralize or deter the threat					

What other objectives do you feel are important in neutralizing IEDs or deterring enemy forces during combat?

14. Which of the following functions are most important in establishing situational awareness in combat?

	Extremely Important (5)	Very Important (4)	Moderately Important (3)	Little Importance (2)	No Importance (1)
Battle Management					
Search					
Identification					
Classification					
Neutralization					
Deterence					

Are there other functions a system should perform to improve situational awareness that are not mentioned above that should be addressed?

15. For this scenario, we are interested in improving our unit's situational awareness in the counter IED fight. Our area of operations is a hot bed for IED emplacers- and one of our primary objectives is identifying individuals in the act of emplacing IEDs, tracking them within our unit's area of operations and neutralizing or deterring the IED. Within the unit's assigned area of operations there are main supply routes (MSR) or lines of communications (LOCs) which connect various forward operating bases (FOBs), out posts (OPs), or local towns. These MSRs and LOCs are traveled numerous times a day by various types of military and civilian vehicles, foot patrols and civilians. These routes are located along side host-nation homes, gardens or fields.

Which of the below methods would be most effective in accomplishing each of the missions listed? Select all that apply

	Soldier on the ground	Unmanned Ground Robotics (MARCBOT, FIDO)	EOD	Small UAVs (Raven)	Medium UAVs (Shadow)	Ground Cameras (GBOSS, JLENS)	No experience in this area
Battle Management							
Search							
Identification							
Classification							
Neutralization							
Deterence							

What other systems have you used that may be effective in this scenario?

16. What systems have you used that you believe may be ineffective in this scenario?

Closing

17. Thank you for your participation in this survey!

We are very interested in any further information, guidance or suggestions you would like to contribute to this research in improving situational awareness in the counter IED fight:

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APPENDIX B. KEY MILITARY CONTRIBUTORS

The following Army officers provided insight to this research via classified and unclassified e-mail communications, survey responses, and telephone conversations.

- LTC Del Hall: deployed twice, once as an Infantry Battalion Commander, once on a Division Staff.
- LTC Mark Walters: deployed twice, once as a RSTA Battalion Commander, once as a JIEDDO Support Team Leader to MND-B HQ.
- LTC James Salome: deployed twice, once as a Brigade Combat Team (BCT) Training Officer (S3), once as a Battalion S3.
- LTC Frederick Wintrich: deployed twice, once as a BCT Executive Officer (XO), once as an Infantry Battalion XO.
- LTC Rob Haycock: deployed once as an Infantry Battalion Commander.
- LTC Thomas Kunk: deployed twice, once as an Infantry Battalion Commander, once as an Infantry Battalion XO.
- LTC William Krahling: deployed twice, once as a Brigade Support Battalion (BSB) Commander, once as a BSB XO.
- LTC Anthony Coston: deployed twice, once as a Divisional Staff Planner, once as a BSB XO.
- MAJ Jimmy Mills: deployed once as a BSB S3.

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LIST OF REFERENCES

Afghan Conflict Monitor. (2008, November). The joint improvised explosive device defeat organization: DoD's fight against IEDs today and tomorrow. Retrieved 4 February 2009 from http://www.afghanconflictmonitor.org/JIEDDO_afghanistanIEDnov2008.JPG.

Atkinson, R. (2007, September 30). The single most effective weapon against our deployed forces. *Washington Post*, p. A01.

Belarus.by. (n.d). Belarus during the great patriotic war. Retrieved 4 February 2009 from http://www.belarus.by/en/belarus/history/11/index3.php.

Blanchard, B.S., & Fabrycky, W.J. (2006). *Systems engineering and analysis* (4th ed.). Upper Saddle River, NJ: Prentice Hall.

Brock, T., & Gammache, I. (2007). Master's thesis (Secret). Naval Postgraduate School, Monterey, CA.

Buede, D.M. (2000). *The engineering design of systems: Models and methods.* Wiley series in Systems Engineering. A.P. Sage (series ed.). Fairfax, VA: John Wiley & Sons, Inc.

Burlas, J. (2004, October 13). JLENS RAID provides commanders persistent stare capability. *ARNEWS Army News Service.* Retrieved 20 December 2008 from http://www4.army.mil/ocpa/read.php?story_id_key=6448.

Clifton, M. (2005, September 14). Tiny robot carries big responsibility in Iraq. Retrieved 18 August 2008 from http://www.defenselink.mil/transformation/articles/2005-09/ta091405a.html.

Department of Defense. (1998, March 17). Joint tactics, techniques, and procedures for antiterrorism. Joint Publication 3-07.2. Washington, D.C.

Department of Defense. (2001, April 12). Department of Defense dictionary of military and associated terms. Joint Publication 1-02 as amended through 17 October 2008. Washington, D.C.

Department of Defense. (2006, September 17). Joint operations. Joint Publication 3-0. Washington, D.C.

Dragonfly Pictures. DP-5X Wasp comparison chart. Retrieved 27 January 2009 from http://67.15.211.8/~dragonf5/index.php?option=com_content&task=view&id=11&Itemid=11.

Eisler, P. (2007, August 2). The vehicle the Pentagon wants and a small S.C. company's rush to make it. *USA Today*, p. 1A.

Endsley, M.R., & Garland, D.J. (2000). *Situation awareness analysis and measurement*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Endsley, M.R. (1995, March). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 37(1), pp. 32-6.

Exponent Engineering and Scientific Consulting. (2008). MARCbot capabilities. Retrieved 16 August 2008 from http://exponentwc.staged.hubbardone.com/marcbot_product/.

Foster-Miller Corporation. (2007). Products and services: TALON family of military, tactical, EOD, MAARS, hazmat, SWAT and dragon runner robots. Retrieved 16 August 2008 from http://www.foster-miller.com/lemming.htm.

Frost & Sullivan. (2005, April 15). UAV remote sensors- proven performance boosts market growth. Retrieved 16 August 2008 from http://www.defense-aerospace.com/article-view/feature/55665/remote-sensors-boost-uav-market-growth.html.

GlobalSecurity.org. (2005a). MULE. Retrieved 22 January 2009 from http://www.globalsecurity.org/military/systems/ground/fcs-mule.htm.

GlobalSecurity.org. (2005b). Shadow. Retrieved 9 January 2009 from http://www.globalsecurity.org/intell/systems/shadow.htm.

GlobalSecurity.org. (2005c). TSAT. Retrieved 19 November 2008 from http://www.globalsecurity.org/space/systems/tsat.htm accessed 19 Nov 08.

GlobalSecurity.org. (2008). Ammunition. Retrieved 22 January 2009 from http://www.globalsecurity.org/military/systems/munitions/bullets2-shaped-charge.htm.

Goebel, G. (2009, January 1). Unmanned aerial vehicles v1.5. Retrieved 9 January 2009 from http://www.vectorsite.net/twuav.html.

Govers, F.X. (2008). The MULE: Multipurpose logistics vehicle: Anatomy of a U.S. Army warrior bot. *Robot Magazine*. Retrieved 22 February 2009 from http://www.botmag.com/articles/mule.shtml.

Grabianowski, E. (2005). How military robots work. *HowStuffWorks.com.* Retrieved 18 August 2008 from http://science.howstuffworks.com/military-robot2.htm.

Headquarters, Department of the Army. (1997, May). Staff organization and operations. Field Manual 101-5. Arlington, VA: U.S. Army Publishing Agency.

Headquarters, Department of the Army. (1998, May). Mine/countermine operations. Field Manual 20-32. Arlington, VA: U.S. Army Publishing Agency.

Headquarters, Department of the Army. (2000, August). Combined-Arms breaching operations. Field Manual 3-34.2. Arlington, VA: U.S. Army Publishing Agency.

Headquarters, Department of the Army. (2001, August). Multiservice procedures for unexploded ordnance operations. Field Manual 3-100.38. Arlington, VA: U.S. Army Publishing Agency.

Headquarters, Department of the Army. (2003). Army satellite communications architecture book. Arlington, VA: U.S. Army Publishing Agency.

Headquarters, Department of the Army. (2004, September). Operational terms and graphics. Field Manual 1-02. Arlington, VA: U.S. Army Publishing Agency.

Headquarters, Department of the Army. (2005, September). Improvised explosive device defeat. Field Manual 3-34.119. Arlington, VA: US Army Publishing Agency.

Hodge, N. (2006, June 21). U.S. soldiers back aerial fix for IEDs. *Jane's Defense Weekly*, Vol 3.

Icasualties.org. (2008). Deaths caused by IED: Iraq coalition casualty count 2008. Retrieved 12 August 2008 from http://icasualties.org/Iraq/IED.aspx.

ICX technologies. (2008). *Fidoonboard white paper: Integrating the FIDO explosives detection sensor with robotic vehicles.* Retrieved 18 August 2008 from http://www.icxt.com/uploads/file/white-papers/FidoOnboard-Integration.pdf.

IEDrobot.com. (2006). Counter IED tools for the warfighter. Retrieved 22 February 2009 from http://www.iedrobot.com/marcbot/marcbotindex.htm.

JIEDDO (2008). Attack the network-defeat the device-train the force. Retrieved 19 November 2008 from https://wwwijieddo.dod.mil.

Kappenman, J. (2008). Army unmanned aircraft systems: Decisive in battle. *Joint Force Quarterly*, Issue 49, 2nd Quarter. Retrieved 1 November 2008 from http://www.army.mil/professionalwriting/volumes/volume6/april_2008/4_08_2.html.

Katzman, J. (2006, February 2). Special report: The USA's transformational communications satellite system (TSAT). Retrieved 24 December 2008 from http://www.windsofchange.net/archives/006660.html.

Kerlin, B. (2009, March 19). Image Resolution. Retrieved 20 March 2009 from http://www.bukisa.com/articles/46703_image-resolution.

Londono, E. (2008, July 10). U.S. troops in Iraq face a powerful new weapon: Use of rocket-propelled bombs spreads. *Washington Post*, p. A01.

Lowe, C. (2007, June 25). Aerial IED busters slammed. *Defense Tech.org*. Retrieved 4 February 2009 from http://www.defensetech.org/archives/003561.html.

Marine Corps Combat Development Command. (2007). G-BOSS operational concept. Coordinating Draft. Combat Development Directorate, Force Protection Integration Division.

Martin, D.H. (2001/2002). A history of U.S. military satellite communication systems. *Crosslink: Space Communications*. 3(1), (Winter).

Naval Satellite Communications Course (NSCC) Study Guide. (2003, September 20). Prepared by AT&T Government Solutions, King George, VA.

Odierno, R. (2007, June 15). Counterinsurgency guidance. Headquarters Multi-National Corps-Iraq, Baghdad, Iraq. Retrieved 27 January 2009 from http://www.airforce.forces.gc.ca/cfawc/Contemporary_Studies/2007/2007-Jun/2007-06-15_Odierno_COIN_guide_e.pdf

Office of the Secretary of Defense. (2005, August 4). Unmanned aircraft systems roadmap 2005-2030. Washington, D.C.: Department of Defense.

Office of the Secretary of Defense. (2007, December 10). Unmanned systems roadmap 2007-2032. Washington, D.C.: Department of Defense.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. (2008, November). Report of the joint defense science board intelligence science board task force on integrating sensor-collected intelligence. Washington, D.C.

Olean, R. (2008, November 7). Flying under the radar: Raven migrating to a new digital data link. Techonology Systems and Program Integration Directorate, NSRDEC. Retrieved 27 January 2009 from http://www.army.mil/-news/2008/11/07/14025-flying-under-the-radar-raven-migrating-to-a-new-digital-data-link/.

Parsch, A. (2005). Directory of U.S. military rockets and missiles. Appendix 4: Undesignated Vehicles. Retrieved 27 January 2009 from http://www.designation-systems.net/dusrm/app4/tern.html.

Parnell, G.S., Driscoll, P.J., & Henderson, D.L. (2008). *Decision making in systems engineering and management*. Hoboken, NJ: John Wiley & Sons, Inc.

Payan, O.A., & Zigler, R. (2008, June 10). Soldier survivability assessment. Presentation. Research development and engineering command (RDECOM).

Perry, W.L. (2000). Knowledge and combat outcomes. *Military Operations Research*, Vol. 5, No. 1.

Ptak, S., Webster, C., & Wilson, T. (2003). Effective decision-making processes for the Joint Force Commander. Retrieved 22 February 2009 from http://www.au.af.mil/au/awc/awcgate/dod/effective_decision.htm

Racoosin, C. (2006, December 11). WGS Overview. Naval Postgraduate School course presentation: PMW/A 170 Communications Program Office.

Ragsdale, C. (2007). *Spreadsheet modeling & decision analysis.* Mason, OH: Thomson South-Western.

Roush, W. (2008). Xconomy: Business + technology in the exponential economy. Retrieved 27 January 2009 from http://www.xconomy.com/?attachment_id=1631.

Sacramento L5 Society. (2006). NASA photos. Retrieved 18 August 2008 from http://www.ad6uy.com/sac-l5/gallery.html.

Schrady, D., & Olwell, D. (2002). OS4580 Logistics Systems Analysis Course Notes. Naval Postgraduate School Course Notes.

Shala-Esa, A. (2008, October 20). Pentagon postpones big satellite contract till fy10. Reuters.com. Retrieved 21 October 2008 from http://biz.yahoo.com/rb/081020/business_us_pentagon_satellite.html?.v=1.

Simpson, A.J. (2005). Spy games: Robot spies. Retrieved 12 August 2008 from http://www.spygames.com/uav/uavmenu.htm.

Staff Writers. (2008, November 24). Raytheon's JLENS conducts successful design reviews. *Space War*. Retrieved 22 January 2009 from http://www.spacewar.com/reports/Raytheon_JLENS_Conducts_Successful_Design_Reviews_999.html.

United States Army Program Executive Office: Missiles and Space. (2005, June). Joint land attack cruise missile defense elevated netted sensor system–Rapid aerostat initial deployment. Huntsville, AL. Retrieved 22 January 2009 from http://www.msl.army.mil/Fact_Sheets/RAID.pdf.

Waltz, E.L., & Llinas, J. (1990). *Multisensor data fusion*. Norwood, MA: Artech House Inc.

Wilson, C. (2007, November 21). Improvised explosive devices in Iraq and Afghanistan: Effects and countermeasures. Congressional Research Report.

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